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by

Kim Trangbæk Jønsson
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July 2020

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1. Introduction

The purpose of this report is to register the operation and performance of the project building Bolig 2020 for the period of 1 year, from January to December 2019. The building is located in Kildebjerg Søvej 32, Ry.

The aim is the long-term assessment of the indoor environmental quality and energy use of the dwelling. Additionally, the data is examined in order to verify that the systems' and equipment's performance matches their intended operation.

The evaluation of the performance of Bolig 2020 case study is based on a combination of standards and measured data.

The data registration is taking place every 5 minutes, approximately, in all rooms of the dwelling. The registered parameters are the following:

Parameters	**Comments**
Cold water consumption [m^3]	Total amount of water consumption for cold and hot water
Hot water consumption [m^3]	
Energy consumption:	
District heating [MWh]	
Floor heating pump [kWh]	
Nilan system [kWh]	Energy consumption for ventilation and production of sanitary hot water
Control system [kWh]	
Kitchen stove [kWh]	Energy consumption for the operation of 2 ovens and the cooking plate
Refrigerator [kWh]	Energy consumption for the refrigerator, wine cooler and exhaust hood
Quooker [kWh]	
Dish washer [kWh]	
Dryer [kWh]	
Washing machine [kWh]	
Other consumption [kWh]	Includes everything else

Temperature [°C], CO_2 level [ppm], Relative humidity level [%] and Damper opening [min/ max]:
Room 1
Room 2
Room 3
Master Bedroom
Living Room
Kitchen/ Dining Room

Temperature [°C], Relative humidity level [%] and Damper opening [min/ max]:
Utility Room
Bathroom 1 (Master Bedroom)

Temperature [°C] and Damper opening [min/ max]:
Wardrobe closet

For the compact unit:
Outdoor air temperature [°C]
Return air temperature [°C] and relative humidity [%]
Hot water temperature [°C]
Supply air temperature [°C]
Heat pump temperature [°C]
Ventilation speed [steps]

External solar shading, skylight and window activation [0/1] (Automatically & Manually):
Solar shading 1: Master Bedroom – East
Solar shading 2: Master Bedroom – South
Solar shading 3: Living Room – South
Solar shading 4: Living Room – West
Skylight 1: Corridor
Skylight 2: Kitchen
Window: Room 1
Window: Room 3
Window: Kitchen/ Dining Room
Window: Living Room
Window: Master Bedroom

Floor heating actuators for each room [0/1]:
Living Room
Master Bedroom
Wardrobe closet
Bathroom 1 (Master Bedroom)
Kitchen/ Dining Room
Corridor
Room 1
Room 2
Room 3
Bathroom 2 (Corridor)
Utility Room

Supply and return air:
Flow [m^3/h]
Temperature [°C]

Water consumption:
Energy consumption for hot water production [kWh]
Hot water flow [l/h]
Hot water temperature (T1) [°C]
Cold water temperature (T2) [°C]

From the 10th of April more parameters was activated in the data, and are the following:

District heating:
Water consumption [m^3]

Flow [l/h]
Hot water temperature (T1) [°C]
Cold water temperature (T2) [°C]

Floor heating:
Water consumption [m^3]
Flow [l/h]
Hot water temperature (T1) [°C]
Cold water temperature (T2) [°C]

Hot water tank:
Water consumption [m^3]
Flow [l/h]
Hot water temperature (T1) [°C]
Cold water temperature (T2) [°C]

This report includes the registered period between the beginnings of January to the end of December 2019. The data is presented both on a monthly level and for the entire period of 1 year. The indoor environment evaluation is realized on a room basis, while the examined rooms are the most used ones, master bedroom, living room, kitchen and bathroom.

Comments

2. Energy Consumption

2.1 Energy consumption for ventilation and DHW

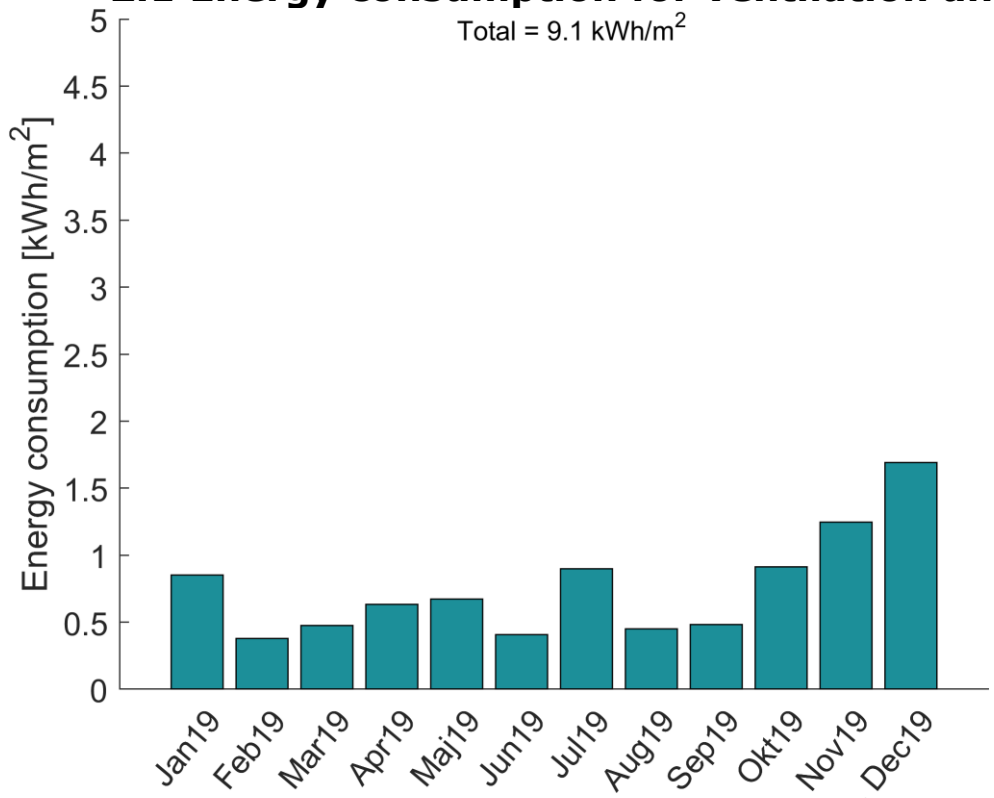


Figure 2.1: Energy consumption for ventilation and domestic hot water [kWh/m^2]

The sanitary hot water is produced by the compact ventilation system through the recovered energy from the exhaust air. If the demand is particularly large, an electrical backup supplements the production of hot water.

2.2 Energy consumption for heating

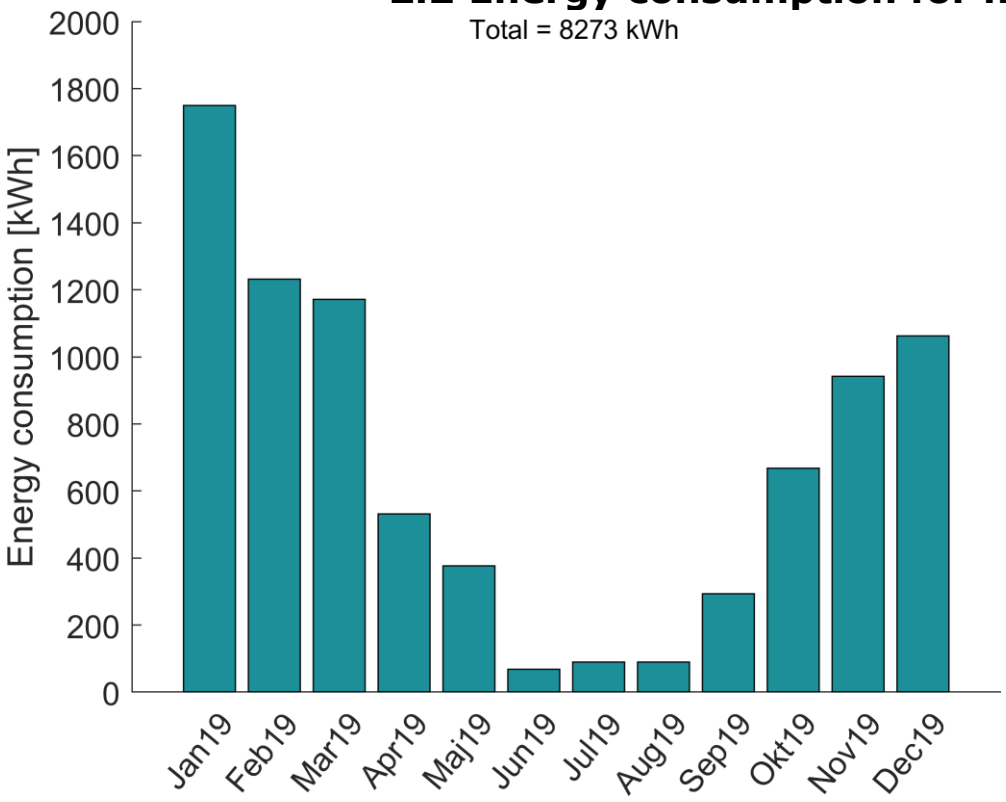


Figure 2.2: Energy consumption for heating [kWh]

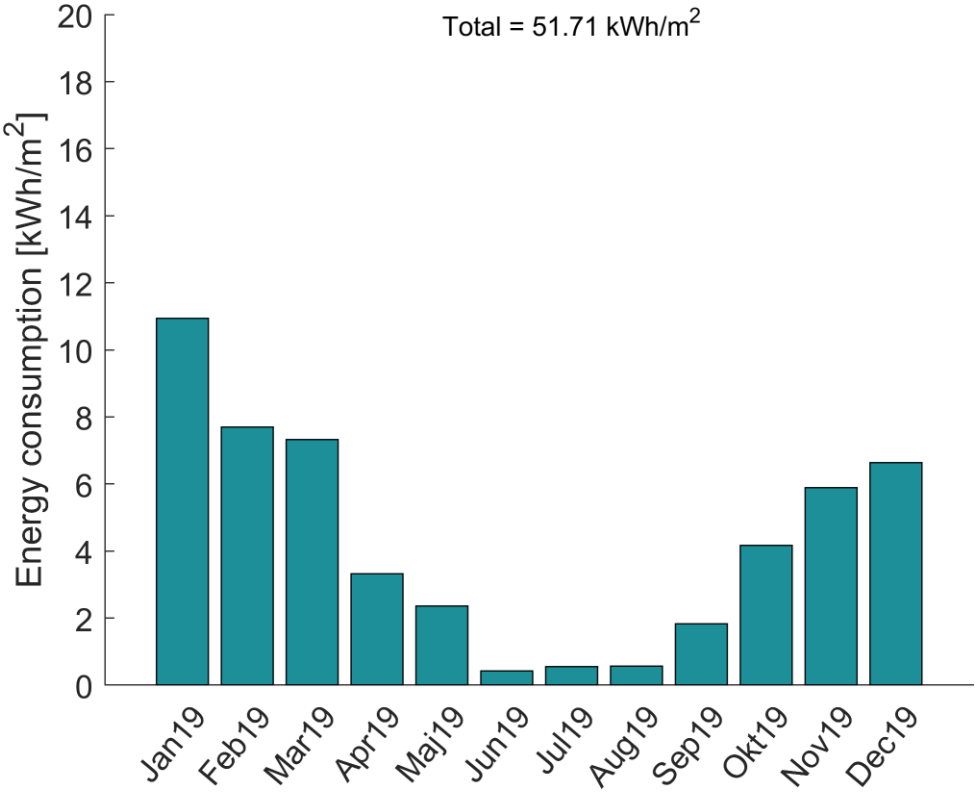


Figure 2.3: Energy consumption for heating [kWh/m^2]

2.3 Electricity consumption

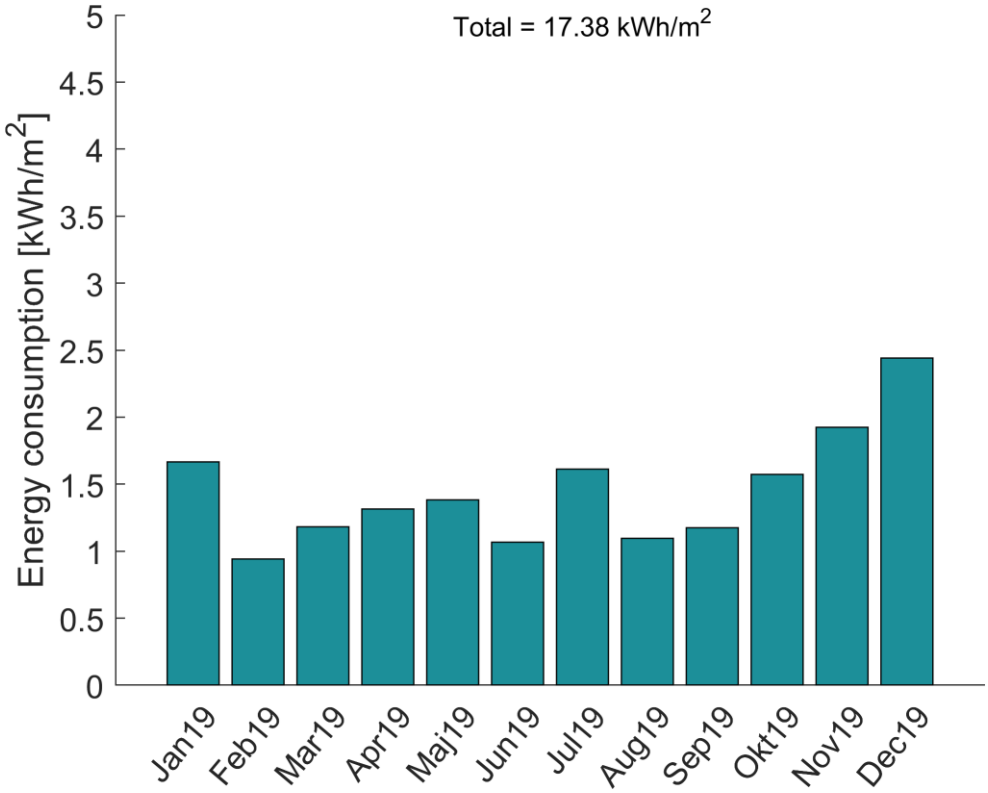


Figure 2.4: Total electricity consumption during the entire year.(White goods, system control, storage tank, floor heating pump, Nilan ventilation unit and the rest) [kWh/m^2]

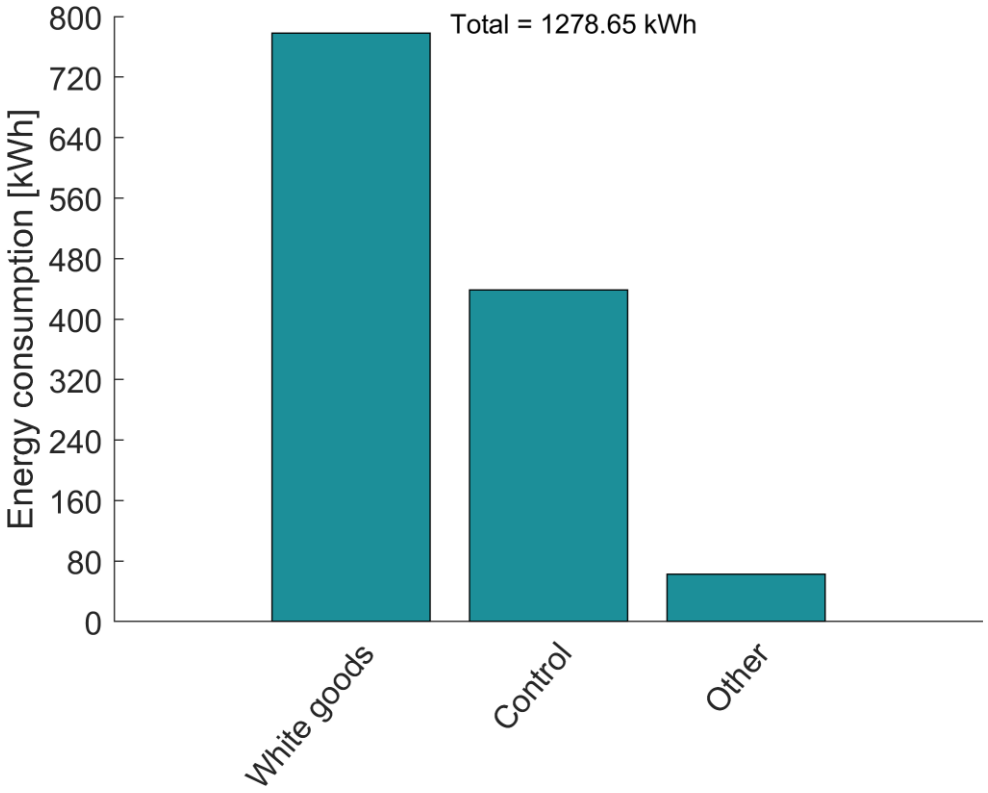


Figure 2.5: Yearly consumption of electricity [kWh]

The energy consumption of white goods includes the kitchen stove, the refrigerator, the Quooker (for production of boiling water), the dishwasher, the dryer and the washing machine. The second column refers to the control of all systems, sensors etc., while the third column includes all the rest.

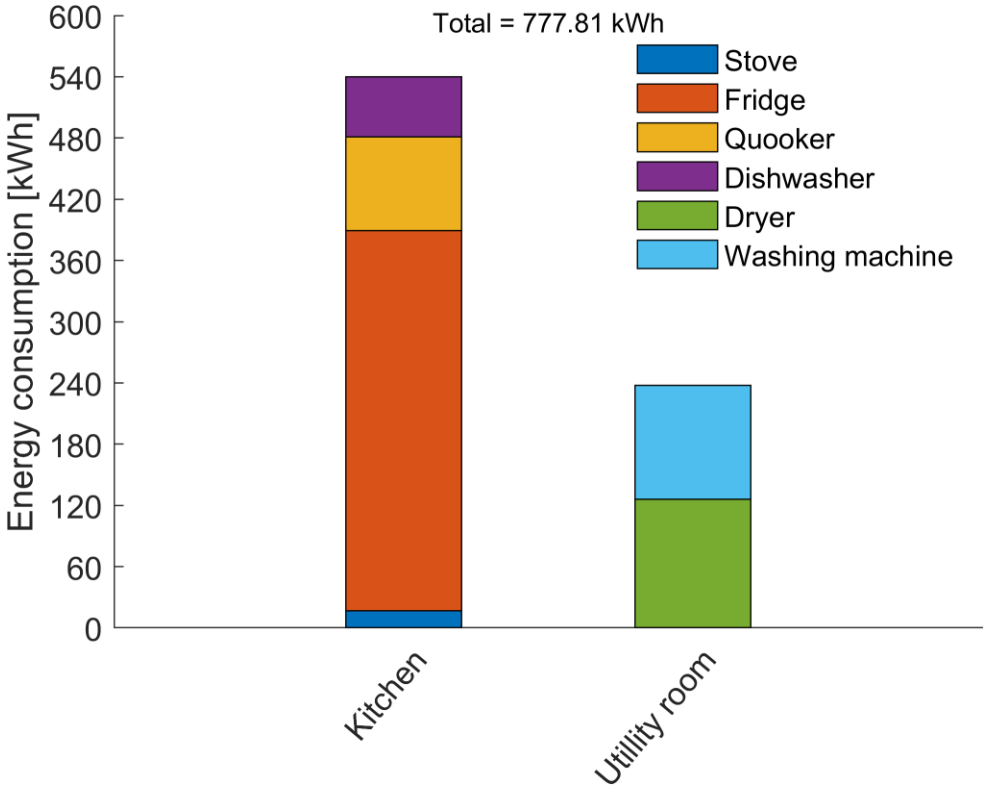


Figure 2.6: Yearly consumption of electricity of white goods, on room level. [kWh]

Figure 2.6 gives the energy consumption for all registered appliances divided in room level.

2.4 Primary energy consumption

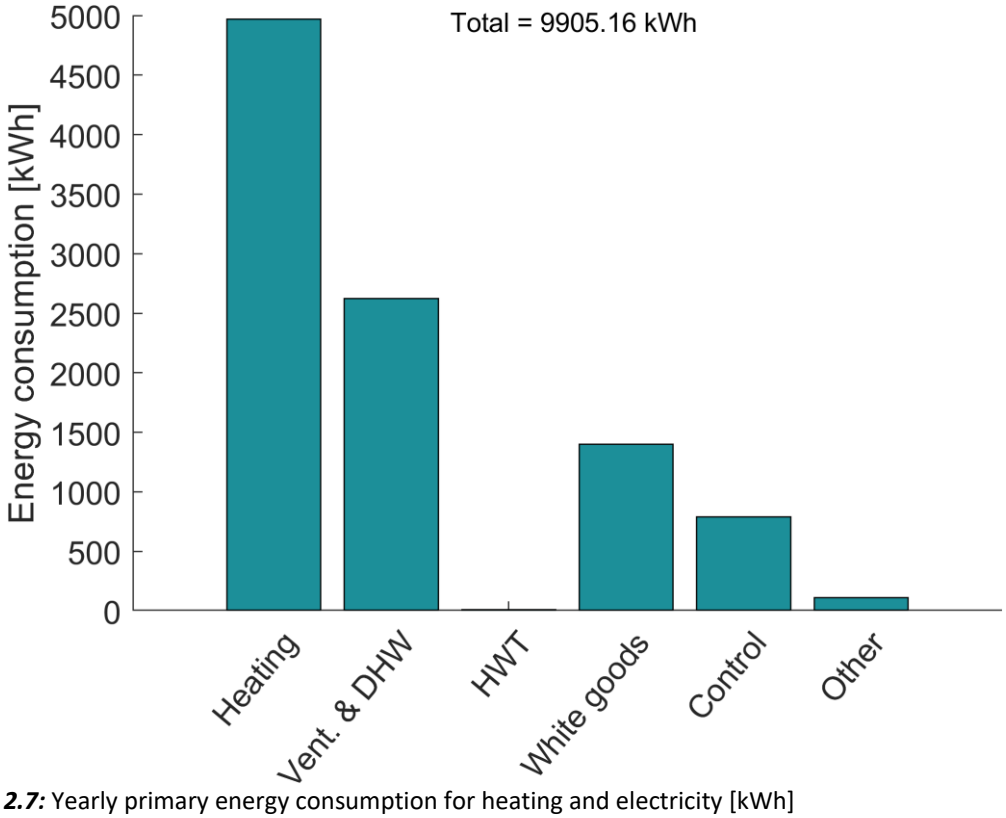


Figure 2.7: Yearly primary energy consumption for heating and electricity [kWh]

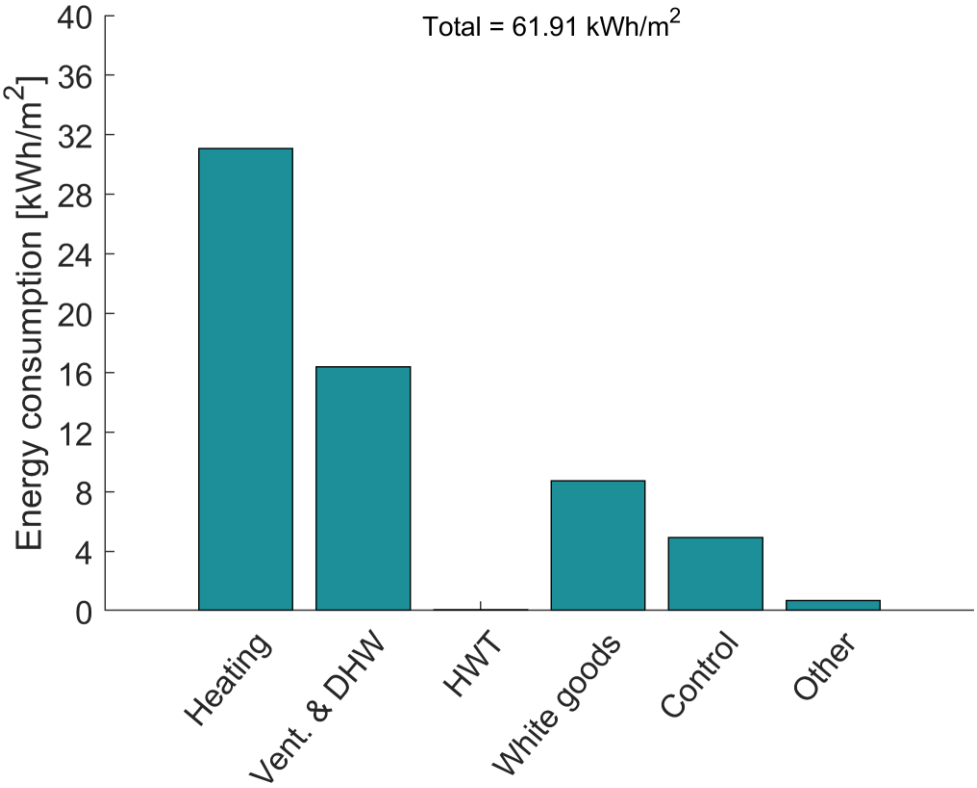


Figure 2.8: Yearly primary energy consumption for heating and electricity [kWh/m^2]]

Figures 2.7 and 2.8 illustrate the primary energy consumption, given in [kWh] and [kWh/m^2], respectively. The values are calculated based on the energy consumption for heating and electricity, multiplied with the primary energy factors, 0.6 and 1.8, respectively.

The graphs include the energy consumption for heating, ventilation and production of domestic hot water, hot water tank, white goods, control of the systems and other.

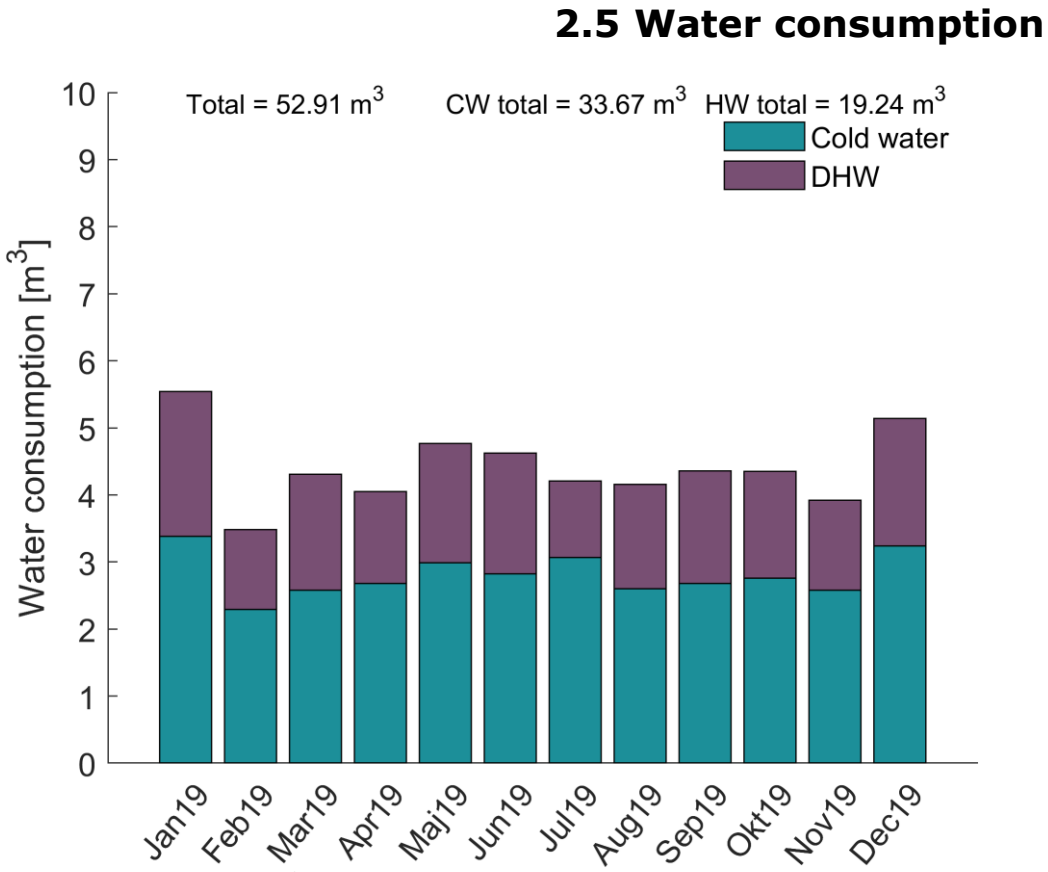


Figure 2.9: Water consumption [m^3]

Part of the total amount of cold water is heated up, giving the hot water consumption.

3. Indoor Environment

For the indoor environmental quality, thermal and atmospheric indoor climate is evaluated. More specifically, the examined parameters are the room temperature [°C], CO_2 level [ppm] and relative humidity level [%]. The rooms are examined on a daily level (24 hours), as well as for their expected occupied period. The time from 7:00 to 17:00 is counted as unoccupied, taking into consideration that the occupants are away from home during this period. The following table sums up the corresponding periods for each type of room.

	Scenario 1	Scenario 2
Living Room	24 h	Day: 17 - 23
Kitchen	24 h	Day: 17 - 23
Master bedroom	24 h	Night: 23 - 7

3.1 Thermal indoor environment

The thermal criteria are assessed according to the comfort categories given by the standards DS/EN 15251. The following table shows the temperature ranges for the three categories, assuming an activity level of 1.2 met (sedentary activity). May to September are calculated for the summer comfort range, while for January to April and October to December are assumed winter conditions.

Activity level [met]		1.2		
Category		I	II	III
Operative temperature [°C]	Summer	24.5 ± 1.0	24.5 ± 1.5	24.5 ± 2.5
	Winter	22.0 ± 1.0	22.0 ± 2.0	22.0 ± 3.0

The recommended criteria for acceptable deviations for the thermal environment, for Category II, are presented in the following table.

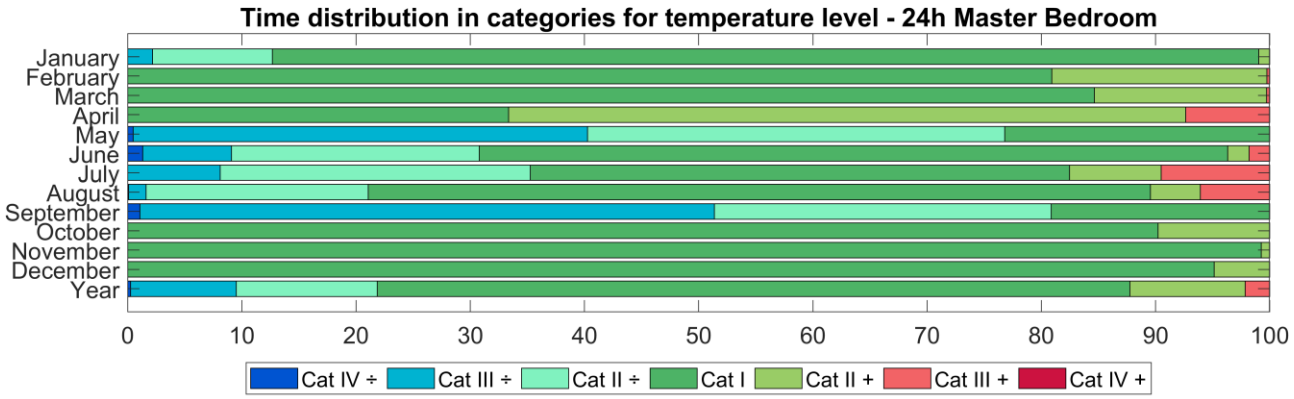
		Max. deviation	
	Criteria	Monthly	Yearly
General Assessment	Class II	3 & 5 %	3 & 5 %
Overheating	25 °C	10 %	10 %
	27 °C	-	100 h
	28 °C	-	25 h
Under heating	20 °C	-	100 h
	19 °C	-	25 h

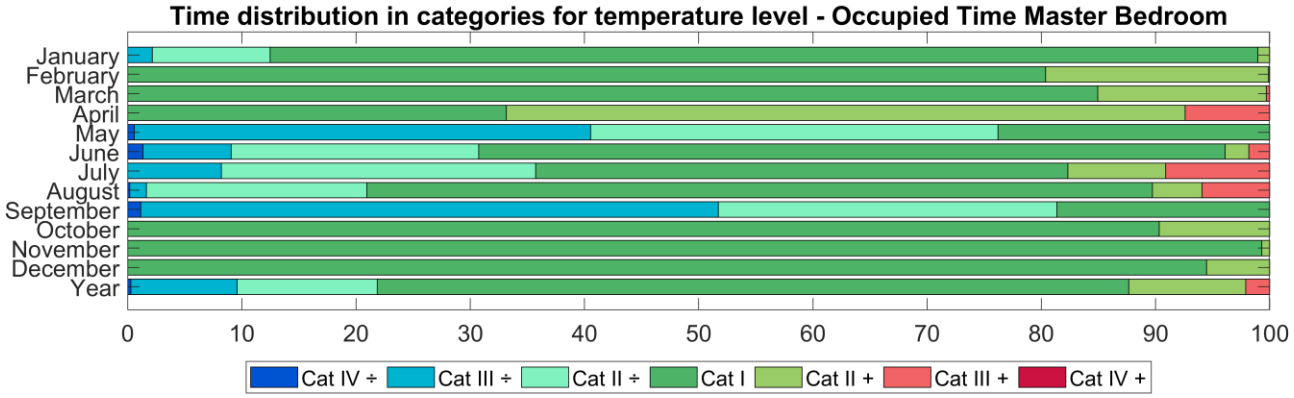
The distribution of hours in each of the three categories is given in percentages, in form of bar charts, specifying whether the room temperature lies on the low or high part of the scale, for summer and winter period, respectively.

IV-	III-	II-	I	II+	III+	IV+
t < 22	22 ≤ t < 23	23 ≤ t < 23.5	23.5 ≤ t ≤ 25.5	25.5 < t ≤ 26	26 < t ≤ 27	27 < t
t < 19	19 ≤ t < 20	20 ≤ t < 21	21 ≤ t ≤ 23	23 < t ≤ 24	24 < t ≤ 25	25 < t

The category distribution percentages are calculated using the corrected temperature, by subtracting 2 °C.

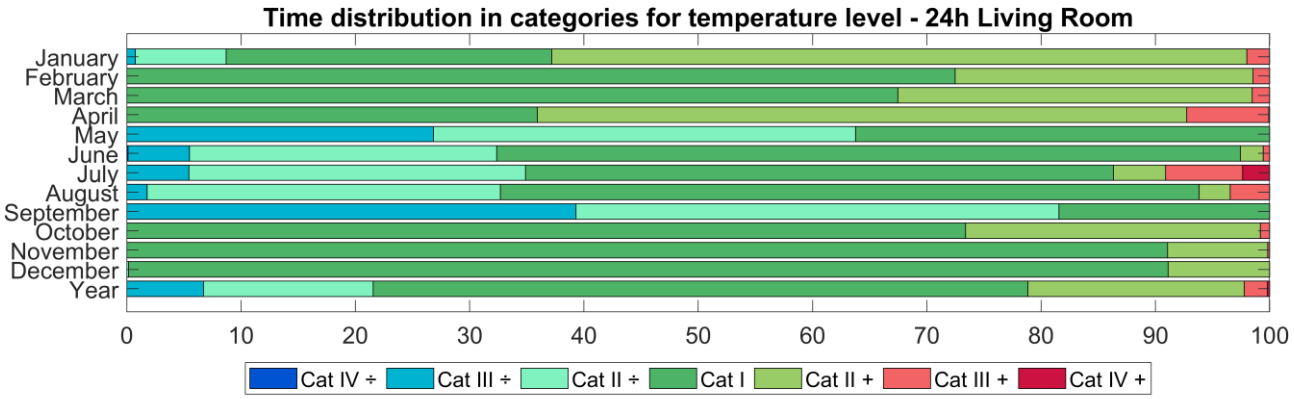
3.1.1 Monthly and yearly categories

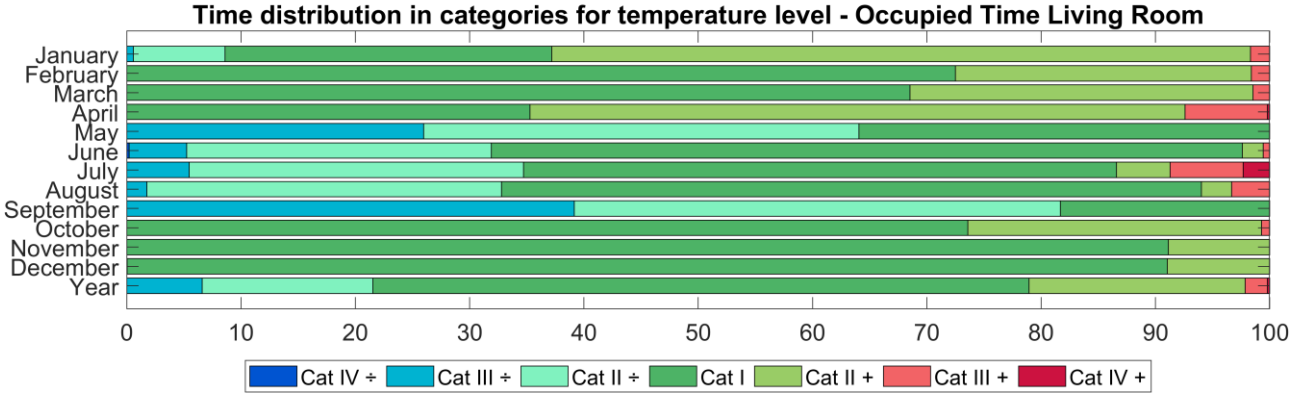




	Categories													
	IV-		III-		II-		I		II+		III+		IV+	
Months	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time
Jan.	-	-	2	2	10	10	86	86	1	1	-	-	-	-
Feb.	-	-	-	-	-	-	81	80	19	20	-	-	-	-
Mar.	-	-	-	-	-	-	85	85	15	15	-	-	-	-
Apr.	-	-	-	-	-	-	33	33	59	59	7	7	-	-
May	-	1	40	40	37	36	23	24	-	-	-	-	-	-
Jun.	1	1	8	8	22	22	66	65	2	2	2	2	-	-
Jul.	-	-	8	8	27	28	47	47	8	9	9	9	-	-
Aug.	-	-	2	1	19	19	68	69	4	4	6	6	-	-
Sept.	1	1	50	51	29	30	19	19	-	-	-	-	-	-
Oct.	-	-	-	-	-	-	90	90	10	10	-	-	-	-
Nov.	-	-	-	-	-	-	99	99	1	1	-	-	-	-
Dec.	-	-	-	-	-	-	95	94	5	6	-	-	-	-
Year	**-**	**-**	**9**	**9**	**12**	**12**	**66**	**66**	**10**	**10**	**2**	**2**	**-**	**-**

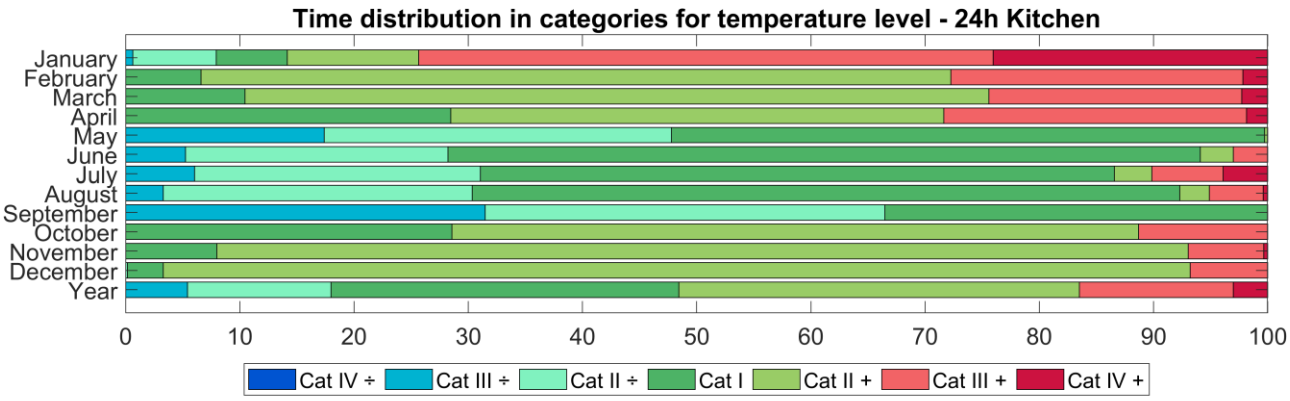
Figure 3.1: Percentage of time in each Category for tempeature (Master bedroom)

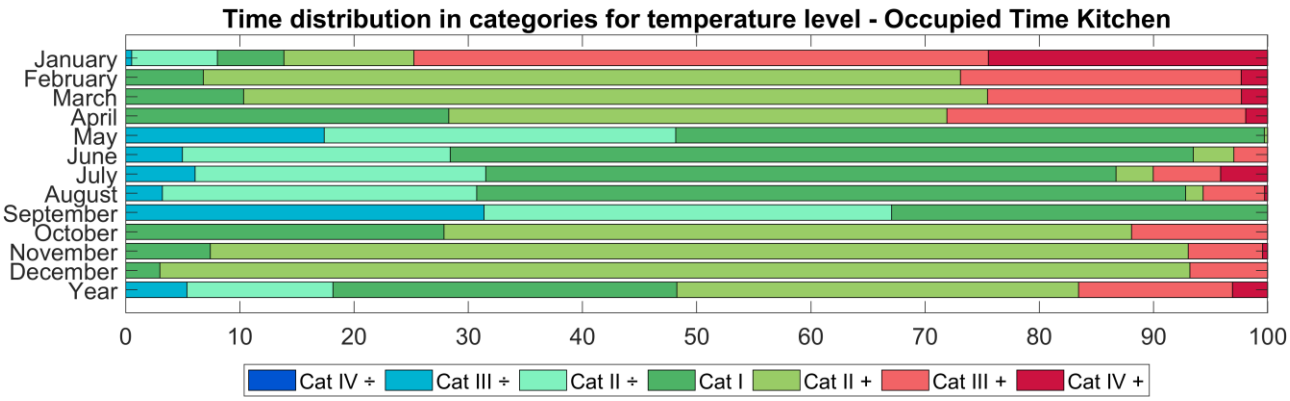




	Categories													
	IV-		III-		II-		I		II+		III+		IV+	
Months	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time
Jan.	-	-	1	1	8	8	28	29	61	61	2	2	-	-
Feb.	-	-	-	-	-	-	72	73	26	26	1	2	-	-
Mar.	-	-	-	-	-	-	67	69	31	30	2	1	-	-
Apr.	-	-	-	-	-	-	36	35	57	57	7	7	-	-
May	-	-	27	26	37	38	36	36	-	-	-	-	-	-
Jun.	-	-	5	5	27	27	65	66	2	2	1	1	-	-
Jul.	-	-	5	5	29	29	51	52	5	5	7	6	2	2
Aug.	-	-	2	2	31	31	61	61	3	3	3	3	-	-
Sept.	-	-	39	39	42	43	18	18	-	-	-	-	-	-
Oct.	-	-	-	-	-	-	73	74	26	26	1	1	-	-
Nov.	-	-	-	-	-	-	91	91	9	9	-	-	-	-
Dec.	-	-	-	-	-	-	91	91	9	9	-	-	-	-
Year	**-**	**-**	**7**	**7**	**15**	**15**	**57**	**57**	**19**	**19**	**2**	**2**	**-**	**-**

Figure 3.2: Percentage of time in each Category for tempeature (Living room)





	Categories													
	IV-		III-		II-		I		II+		III+		IV+	
Months	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time
Jan.	-	-	1	1	7	7	6	6	12	11	50	50	24	24
Feb.	-	-	-	-	-	-	7	7	66	66	26	25	2	2
Mar.	-	-	-	-	-	-	10	10	65	65	22	22	2	2
Apr.	-	-	-	-	-	-	28	28	43	44	27	26	2	2
May	-	-	17	17	30	31	52	52	-	-	-	-	-	-
Jun.	-	-	5	5	23	23	66	65	3	4	3	3	-	-
Jul.	-	-	6	6	25	25	55	55	3	3	6	6	4	4
Aug.	-	-	3	3	27	28	62	62	3	2	5	5	-	-
Sept.	-	-	31	31	35	36	34	33	-	-	-	-	-	-
Oct.	-	-	-	-	-	-	29	28	60	60	11	12	-	-
Nov.	-	-	-	-	-	-	8	7	85	86	7	7	-	-
Dec.	-	-	-	-	-	-	3	3	90	90	7	7	-	-
Year	**-**	**-**	**5**	**5**	**13**	**13**	**30**	**30**	**35**	**35**	**13**	**13**	**3**	**3**

Figure 3.3: Percentage of time in each Category for tempeature (Kitchen)

3.1.2 Yearly categories

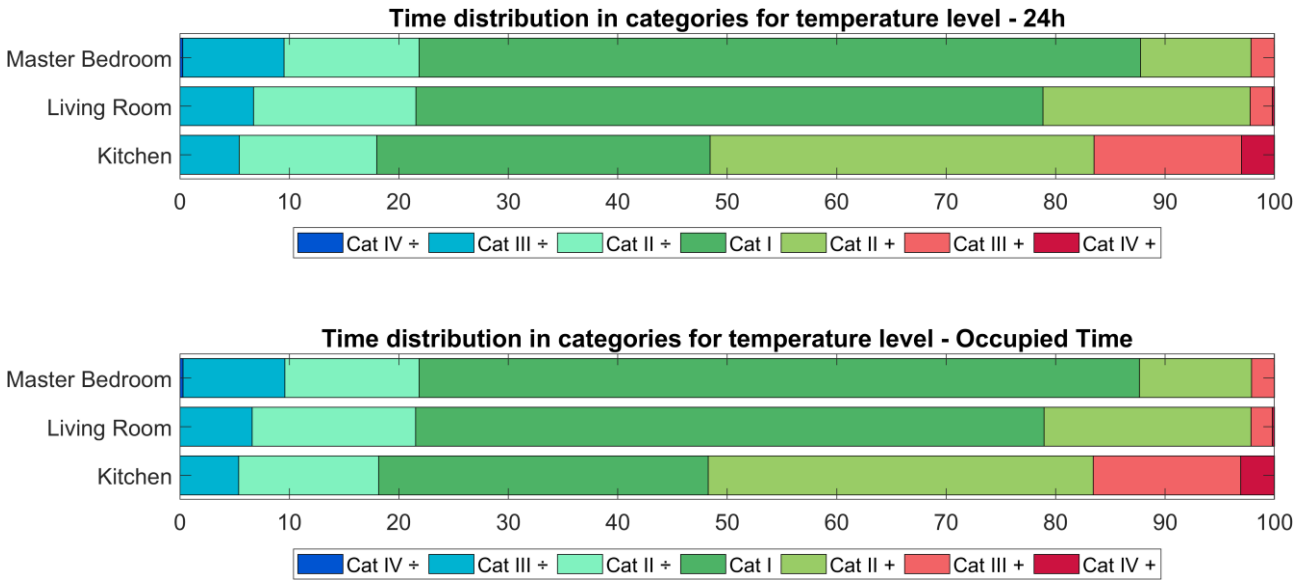


Figure 3.4: Percentage of time in each Category for tempeature during a year

3.1.3 Seasonal temperature distribution

The following graphs present the seasonal temperature distribution for different rooms. The depicted period is from January to the end of September, when there are data concerning the outdoor temperature.

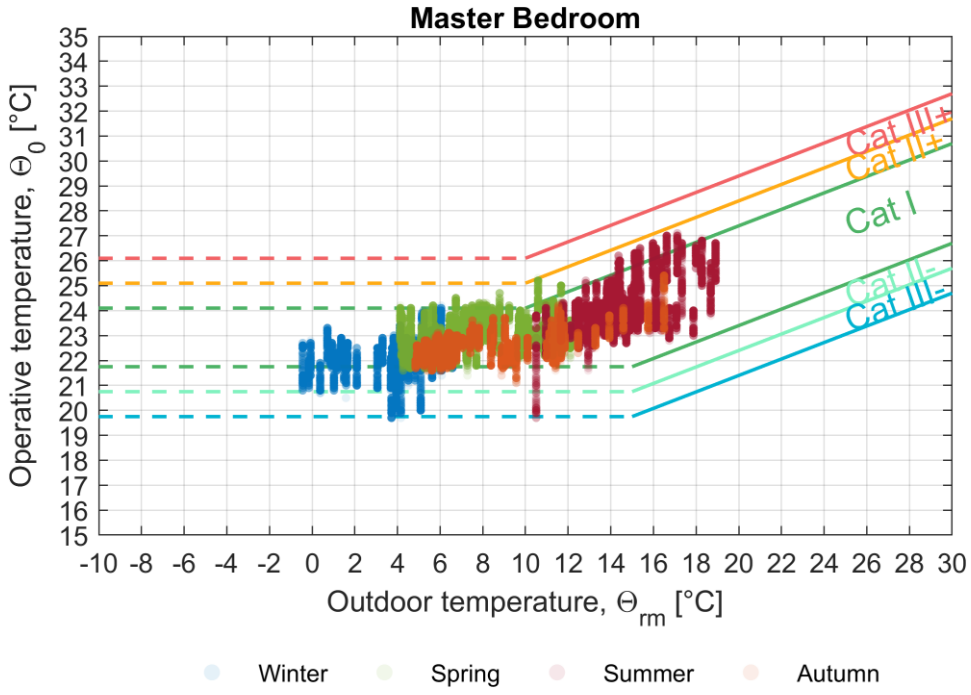


Figure 3.5: Indoor temperature as a function of the running mean outdoor temperature for master bedroom

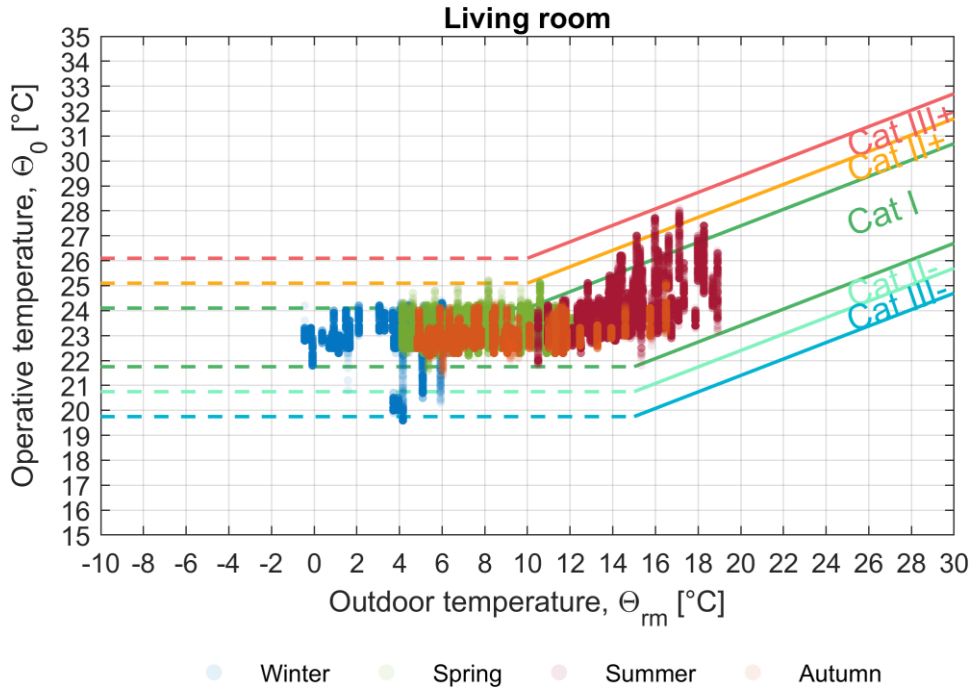


Figure 3.6: Indoor temperature as a function of the running mean outdoor temperature for living room

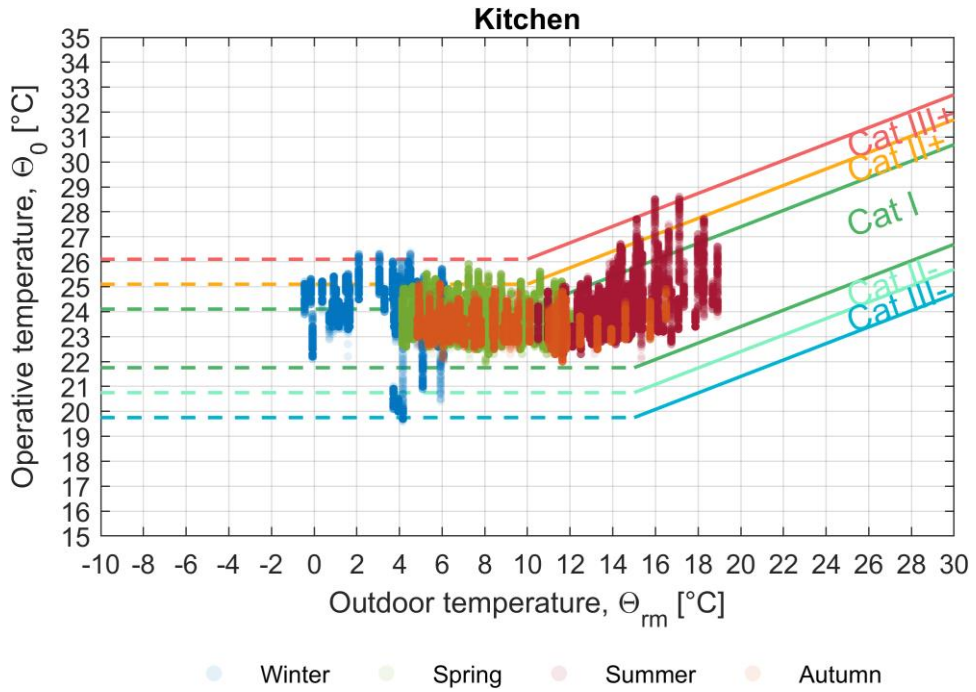


Figure 3.7: Indoor temperature as a function of the running mean outdoor temperature for kitchen

3.1.4 Thermal comfort and window activation

The following graphs are presenting the thermal comfort level, in relation to window opening, on room level. It is considered that comfort conditions are met when the criteria for Category II are fulfilled. The activation of windows can be realized either automatically or manually. For the kitchen/ dining room, the skylight is also taken into consideration, apart from the window.

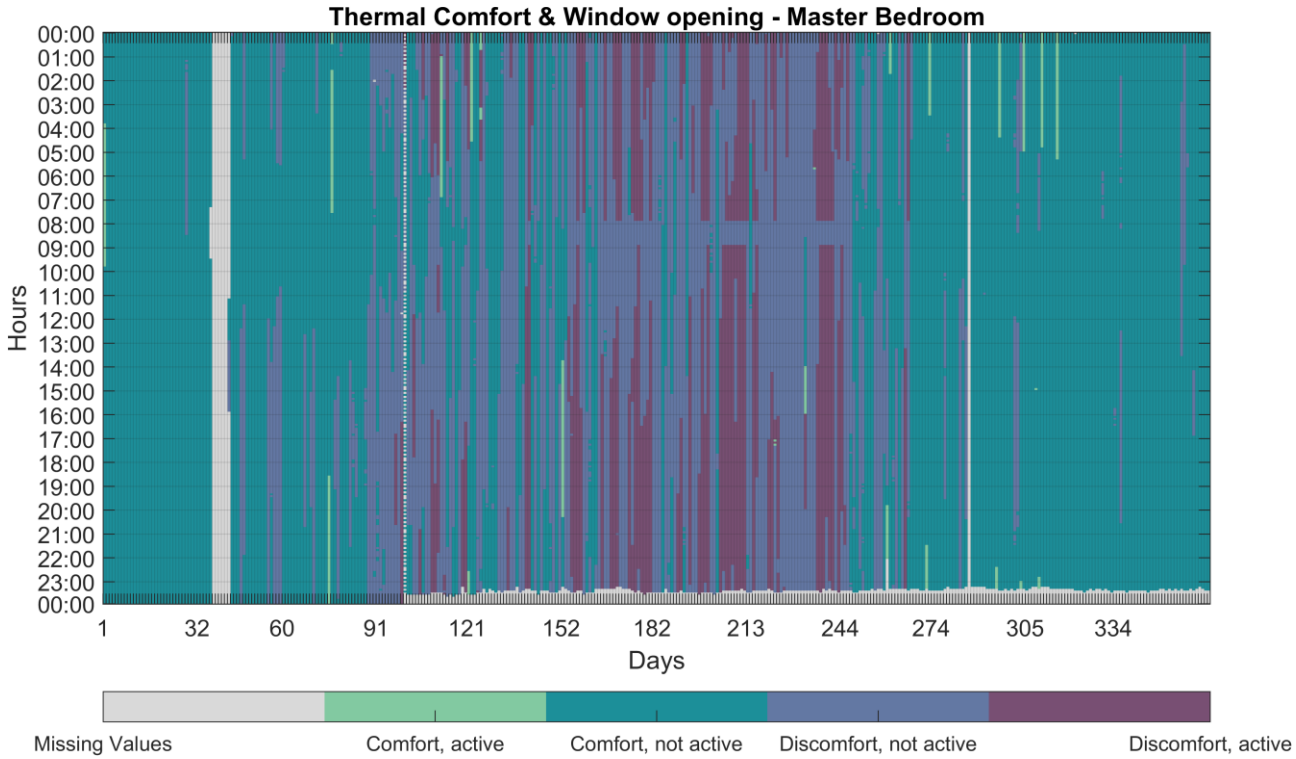


Figure 3.8: Thermal comfort in relation to window opening – Master bedroom

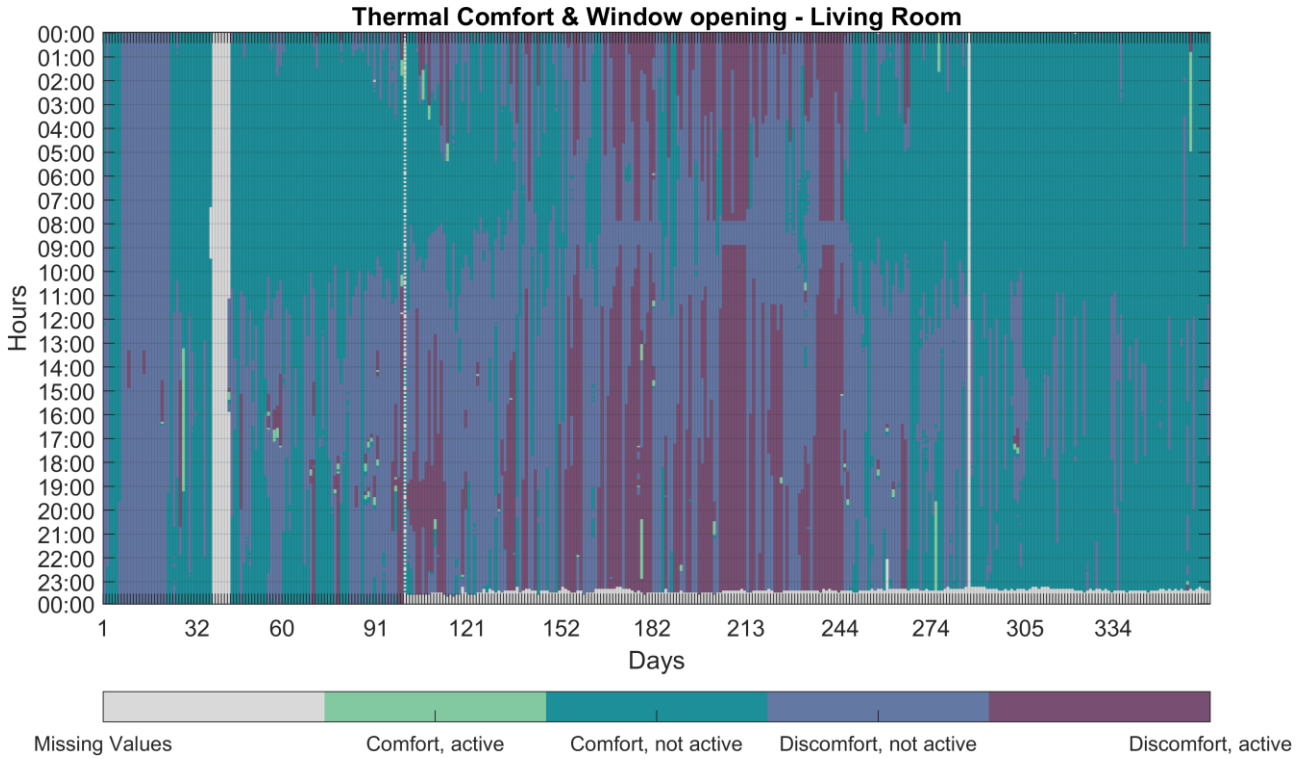


Figure 3.9: Thermal comfort in relation to window opening – Living room (December)

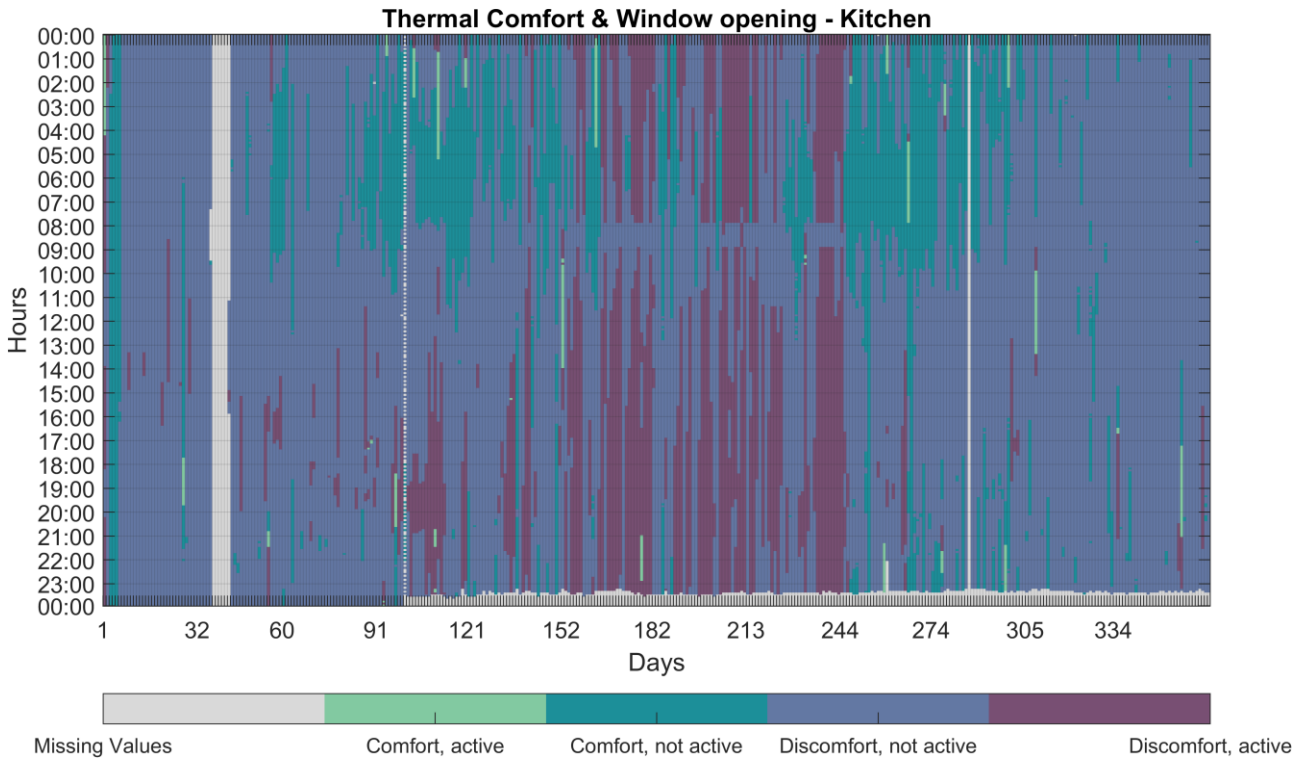


Figure 3.10: Thermal comfort in relation to window opening – Kitchen/ Dining room (December)

3.1.5 Thermal comfort and shading activation

The following graphs are presenting the thermal comfort level, in relation to shading activation, on room level. It is considered that comfort conditions are met when the criteria for Category II are fulfilled. The activation of the shading devices can be realized either automatically or manually.

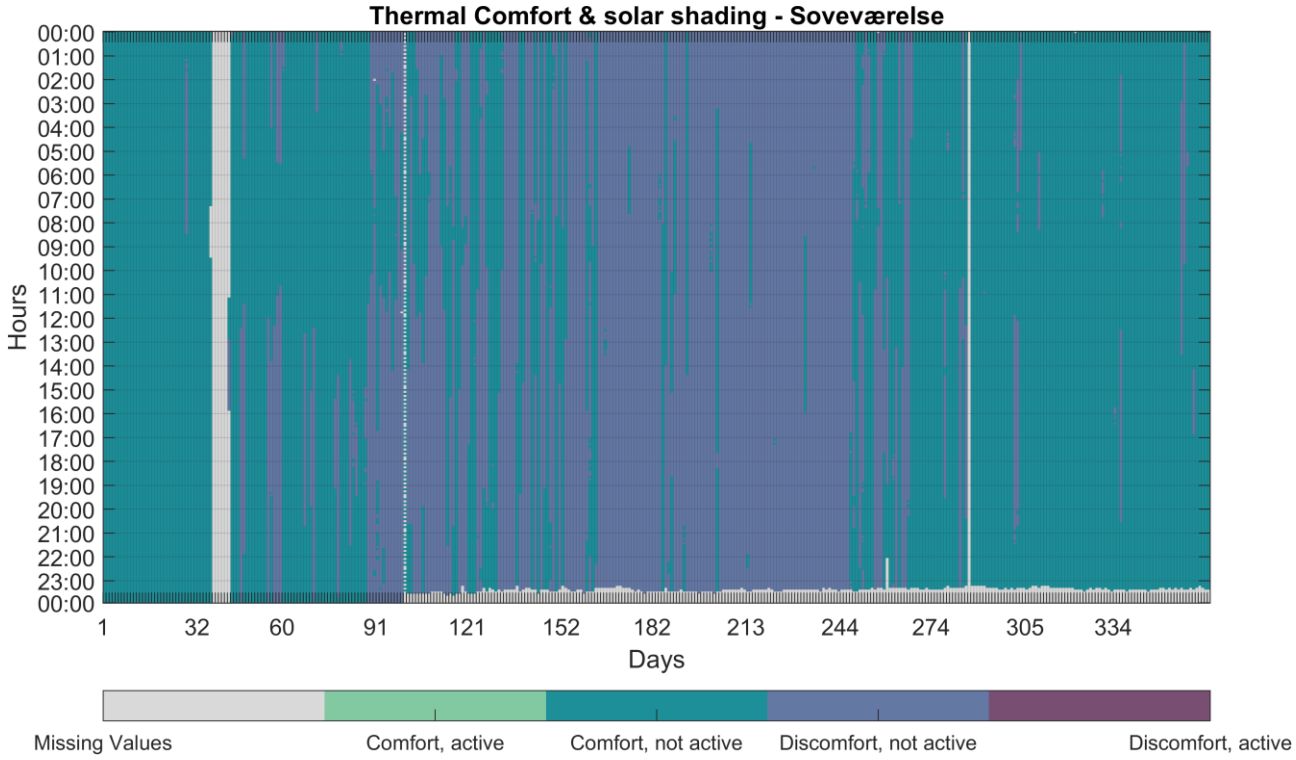


Figure 3.11: Thermal comfort in relation to shading activation – Master bedroom (December)

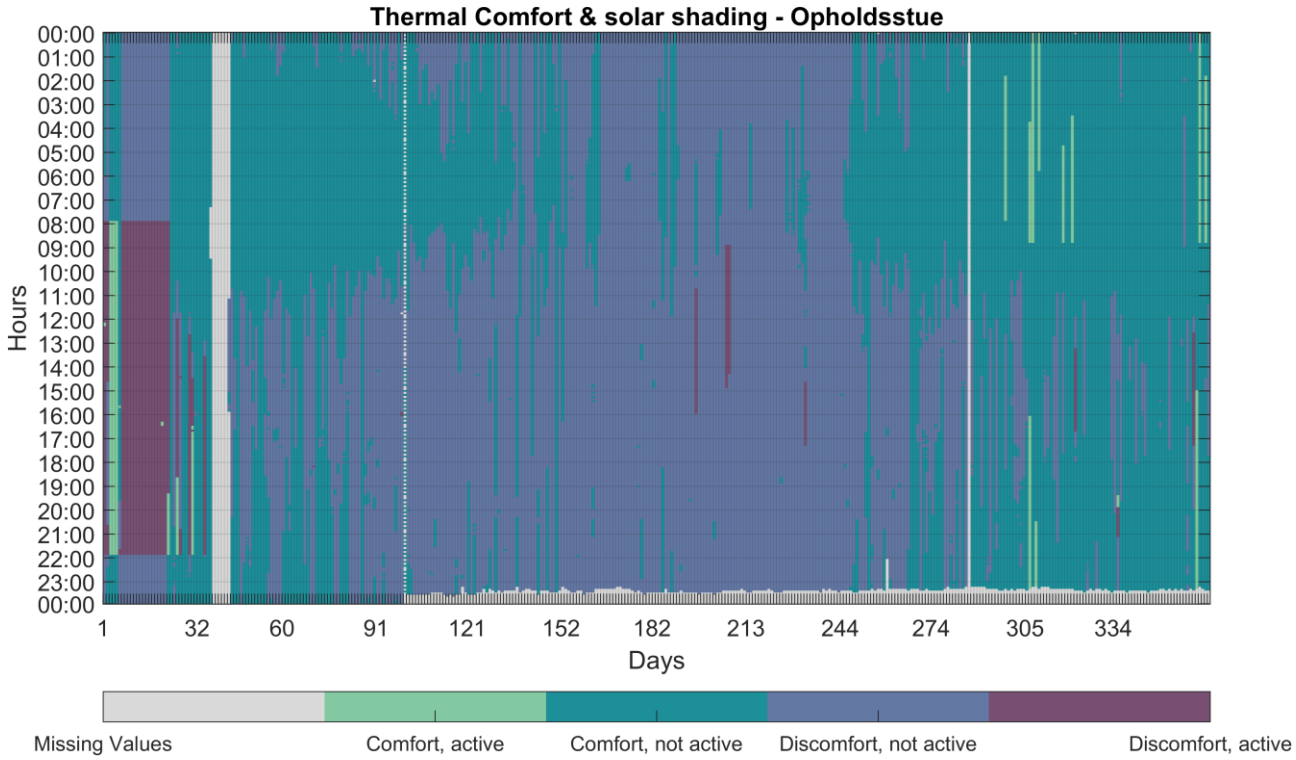


Figure 3.12: Thermal comfort in relation to shading activation – Living room (December)

3.2 Atmospheric indoor environment

The indoor air quality is also assessed based on the comfort categories suggested by the standards DS/EN 15251. On the following tables are given the acceptable ranges for CO_2 level and relative humidity, respectively.

Category	Corresponding CO_2 above outdoors level [ppm]
I	350
II	500
III	800
IV	> 800

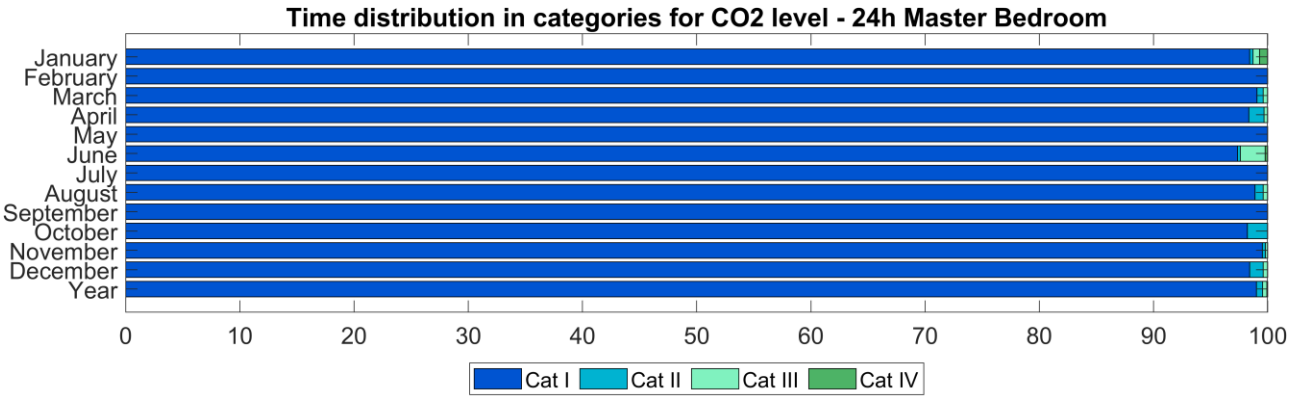
Category	Design relative humidity for dehumidification [%]	Design relative humidity for humidification [%]
I	50	30
II	60	25
III	70	20
IV	>70	<20

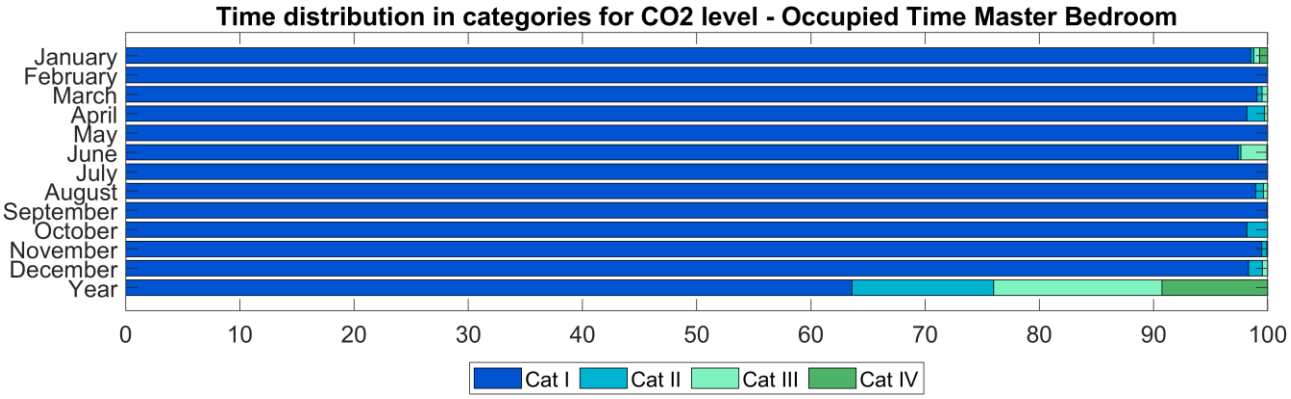
The outdoor CO_2 level is taken as a standard value of 400 ppm and not as the minimum registered value by the sensors in each room. This was decided based on the observation that occasionally some of the sensors would register some unrealistically small values. Actions have been taken in order to verify the proper operation of the sensors and eventually to calibrate or replace them. Therefore, it should be kept in mind that there is some uncertainty concerning the presented results for the CO_2 level.

Next table shows the recommended criteria for acceptable deviations for the atmospheric environment, for Category II.

		Max. deviation
	Criteria	Monthly
CO_2	Category II	3 & 5 %
	Category II	8 h in a row
Relative Humidity	Category II	3 & 5 %
	Category II	24 h in a row
	RH< 45%	-
	RH> 75%	1%

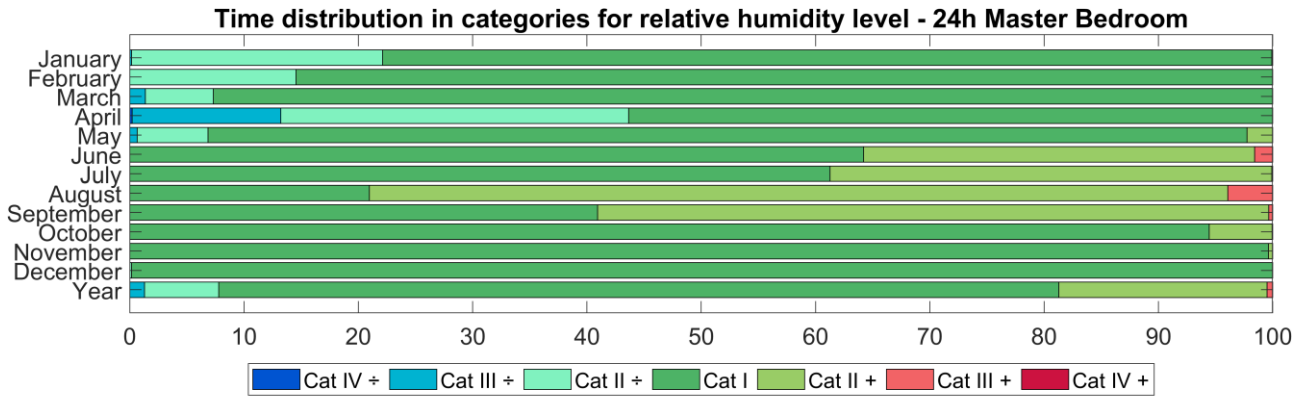
3.2.1 Monthly and yearly categories

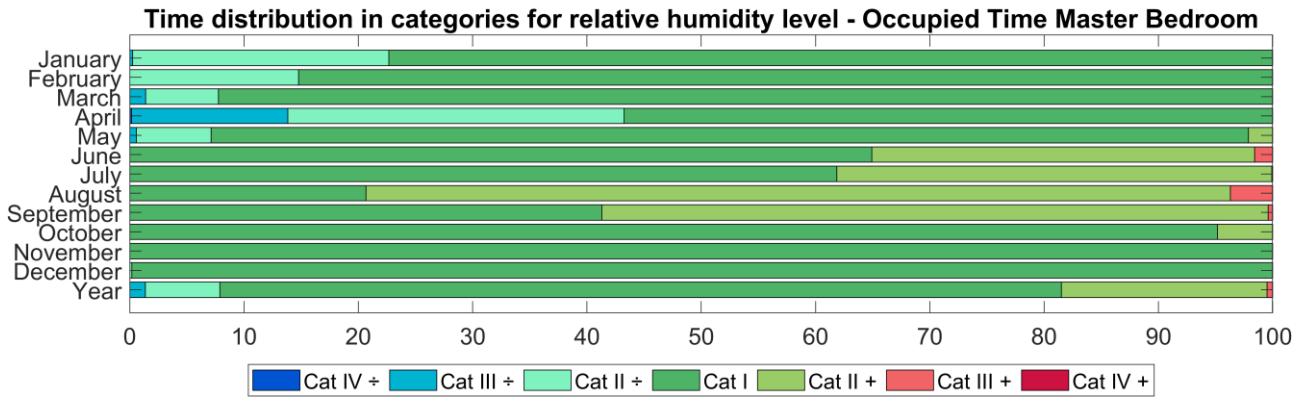




	Categories							
	I		**II**		**III**		**IV**	
Months	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time
January	98	99	0	0	1	0	1	1
February	100	100	0	0	0	0	0	0
March	99	99	1	0	0	0	0	0
April	98	98	1	2	0	0	0	0
May	100	100	0	0	0	0	0	0
June	97	97	0	0	2	2	0	0
July	100	100	0	0	0	0	0	0
August	99	99	1	1	0	0	0	0
September	100	100	0	0	0	0	0	0
October	98	98	2	2	0	0	0	0
November	100	99	0	0	0	0	0	0
December	98	98	1	1	0	0	0	0
Year	**99**	**64**	**1**	**12**	**0**	**15**	**0**	**9**

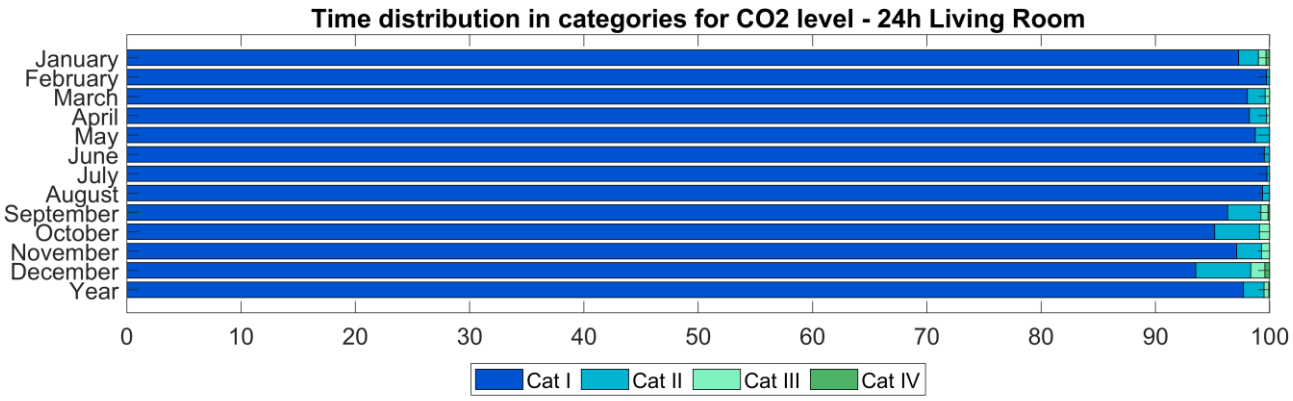
Figure 3.13: Percentage of time in each Category for CO_2 level (Master bedroom)

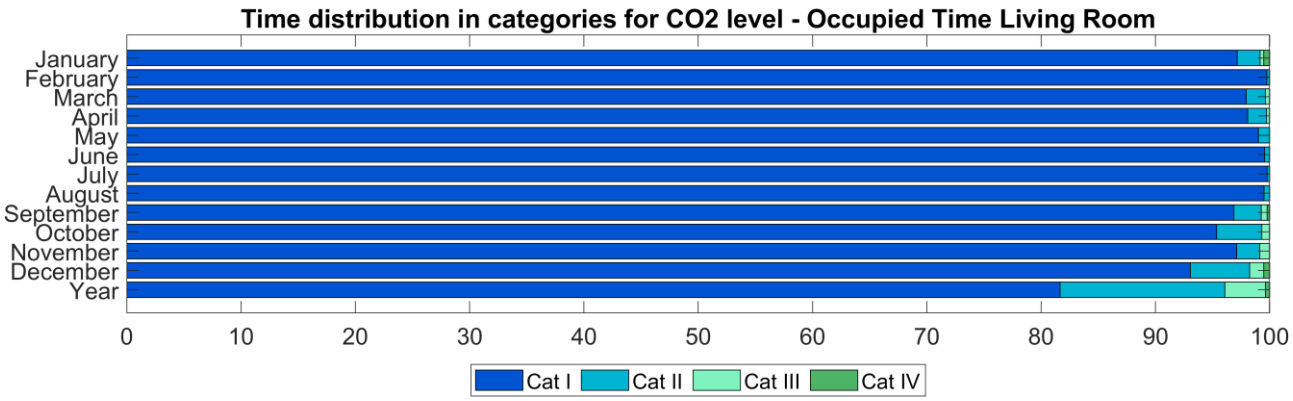




	Categories													
	IV-		III-		II-		I		II+		III+		IV+	
Months	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time
Jan.	-	-	-	-	22	22	78	77	-	-	-	-	-	-
Feb.	-	-	-	-	15	15	85	85	-	-	-	-	-	-
Mar.	-	-	1	1	6	6	93	92	-	-	-	-	-	-
Apr.	-	-	13	14	30	29	56	57	-	-	-	-	-	-
May	-	-	1	1	6	7	91	91	2	2	-	-	-	-
Jun.	-	-	-	-	-	-	64	65	34	33	2	2	-	-
Jul.	-	-	-	-	-	-	61	62	39	38	0	0	-	-
Aug.	-	-	-	-	-	-	21	21	75	76	4	4	-	-
Sept.	-	-	-	-	-	-	41	41	59	58	-	-	-	-
Oct.	-	-	-	-	-	-	94	95	6	5	-	-	-	-
Nov.	-	-	-	-	-	-	100	100	-	-	-	-	-	-
Dec.	-	-	-	-	-	-	100	100	-	-	-	-	-	-
Year	**-**	**-**	**1**	**1**	**6**	**7**	**73**	**74**	**18**	**18**	**1**	**-**	**-**	**-**

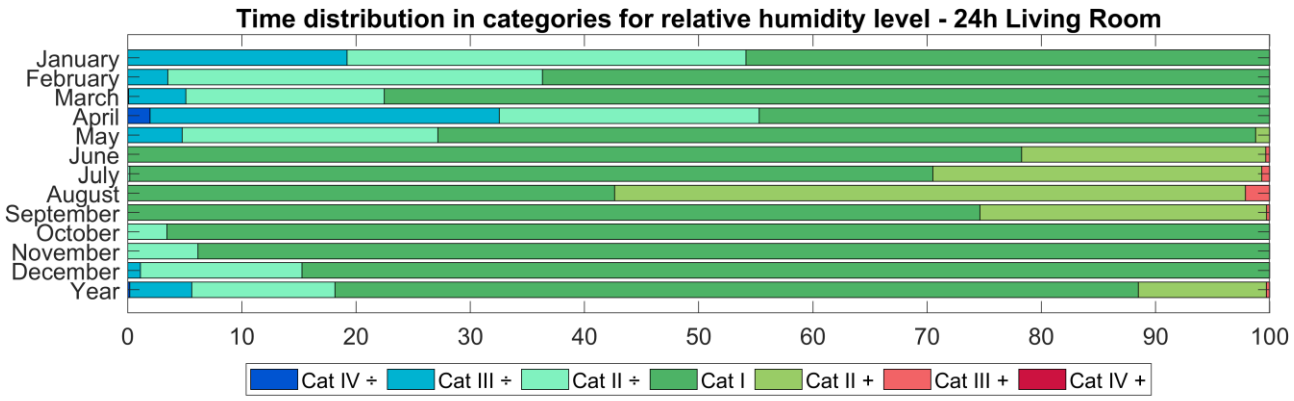
Figure 3.14: Percentage of time in each Category for relative humidity level (Master bedroom)

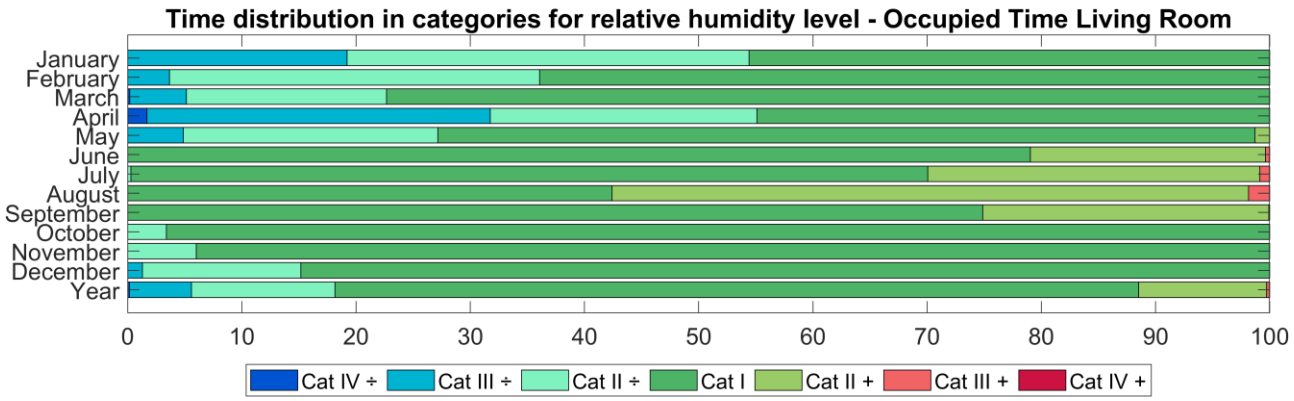




	Categories							
	I		II		III		IV	
Months	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time
January	97	97	2	2	1	0	0	1
February	100	100	0	0	0	0	0	0
March	98	98	2	2	0	0	0	0
April	98	98	2	2	0	0	0	0
May	99	99	1	1	0	0	0	0
June	100	100	0	0	0	0	0	0
July	100	100	0	0	0	0	0	0
August	99	99	1	1	0	0	0	0
September	96	97	3	2	1	1	0	0
October	95	95	4	4	1	1	0	0
November	97	97	2	2	1	1	0	0
December	94	93	5	5	1	1	0	1
Year	**98**	**82**	**2**	**14**	**0**	**4**	**0**	**0**

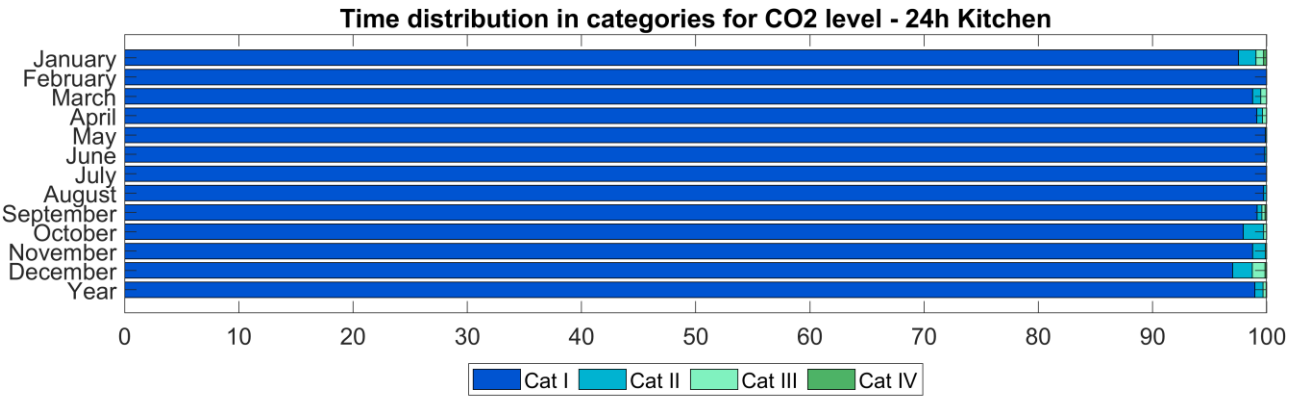
Figure 3.15: Percentage of time in each Category for CO_2 level (Living room)

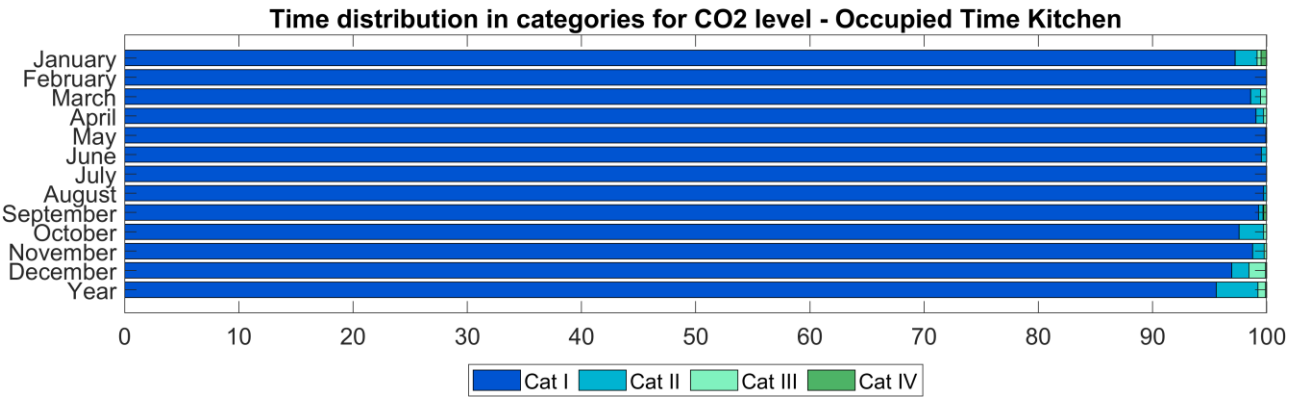




	Categories													
	IV-		III-		II-		I		II+		III+		IV+	
Months	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time
Jan.	-	-	19	19	35	35	46	46	-	-	-	-	-	-
Feb.	-	-	4	4	33	32	64	64	-	-	-	-	-	-
Mar.	-	-	5	5	17	18	78	77	-	-	-	-	-	-
Apr.	2	2	31	30	23	23	45	45	-	-	-	-	-	-
May	-	-	5	5	22	22	72	72	1	1	-	-	-	-
Jun.	-	-	-	-	-	-	78	79	21	21	-	-	-	-
Jul.	-	-	-	-	-	-	70	70	29	29	1	1	-	-
Aug.	-	-	-	-	-	-	43	42	55	56	2	2	-	-
Sept.	-	-	-	-	-	-	75	75	25	25	-	-	-	-
Oct.	-	-	-	-	3	3	97	97	-	-	-	-	-	-
Nov.	-	-	-	-	6	6	94	94	-	-	-	-	-	-
Dec.	-	-	1	1	14	14	85	85	-	-	-	-	-	-
Year	**-**	**-**	**5**	**5**	**13**	**13**	**70**	**70**	**11**	**11**	**-**	**-**	**-**	**-**

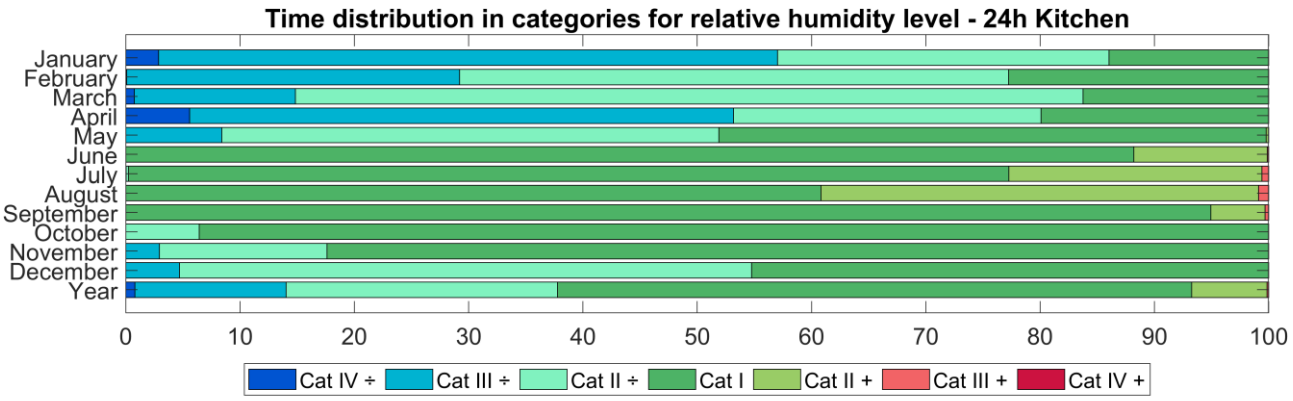
Figure 3.16: Percentage of time in each Category for relative humidity level (Living room)

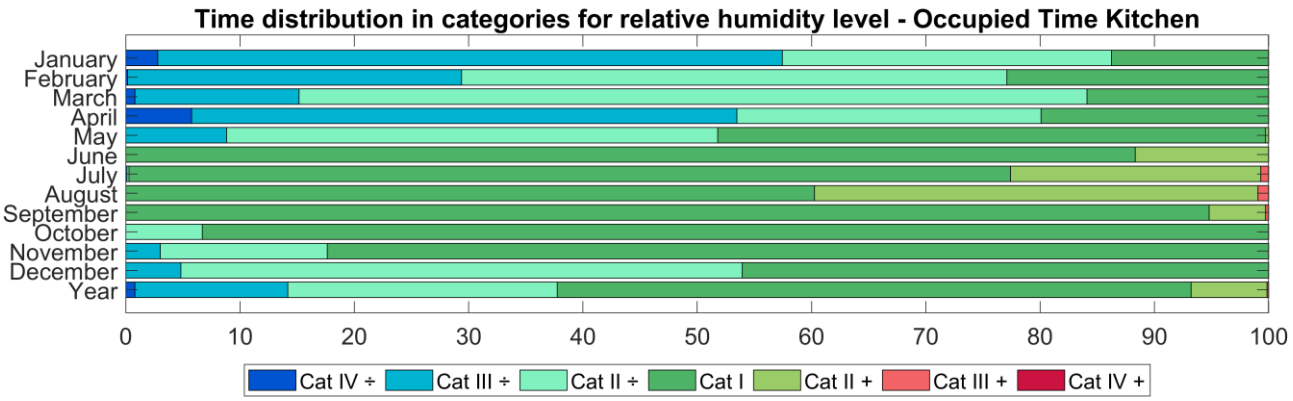




	Categories							
	I		II		III		IV	
Months	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time
January	98	97	2	2	1	0	0	1
February	100	100	0	0	0	0	0	0
March	99	99	1	1	1	1	0	0
April	99	99	0	1	0	0	0	0
May	100	100	0	0	0	0	0	0
June	100	100	0	0	0	0	0	0
July	100	100	0	0	0	0	0	0
August	100	100	0	0	0	0	0	0
September	99	99	0	0	0	0	0	0
October	98	98	2	2	0	0	0	0
November	99	99	1	1	0	0	0	0
December	97	97	2	1	1	1	0	0
Year	**99**	**96**	**1**	**4**	**0**	**1**	**0**	**0**

Figure 3.17: Percentage of time in each Category for CO_2 level (Kitchen)





	Categories													
	IV-		III-		II-		I		II+		III+		IV+	
Months	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time	24 hours	Occup Time
Jan.	3	3	54	55	29	29	14	14	-	-	-	-	-	-
Feb.	-	-	29	29	48	48	23	23	-	-	-	-	-	-
Mar.	1	1	14	14	69	69	16	16	-	-	-	-	-	-
Apr.	6	6	48	48	27	27	20	20	-	-	-	-	-	-
May	-	-	8	9	43	43	48	48	-	-	-	-	-	-
Jun.	-	-	-	-	-	-	88	88	12	12	-	-	-	-
Jul.	-	-	-	-	-	-	77	77	22	22	1	1	-	-
Aug.	-	-	-	-	-	-	61	60	38	39	1	1	-	-
Sept.	-	-	-	-	-	-	95	95	5	5	-	-	-	-
Oct.	-	-	-	-	6	7	94	93	-	-	-	-	-	-
Nov.	-	-	3	3	15	15	82	82	-	-	-	-	-	-
Dec.	-	-	5	5	50	49	45	46	-	-	-	-	-	-
Year	**1**	**1**	**13**	**13**	**24**	**24**	**55**	**55**	**7**	**7**	**-**	**-**	**-**	**-**

Figure 3.18: Percentage of time in each Category for relative humidity level (Kitchen)

3.2.2 Yearly Categories

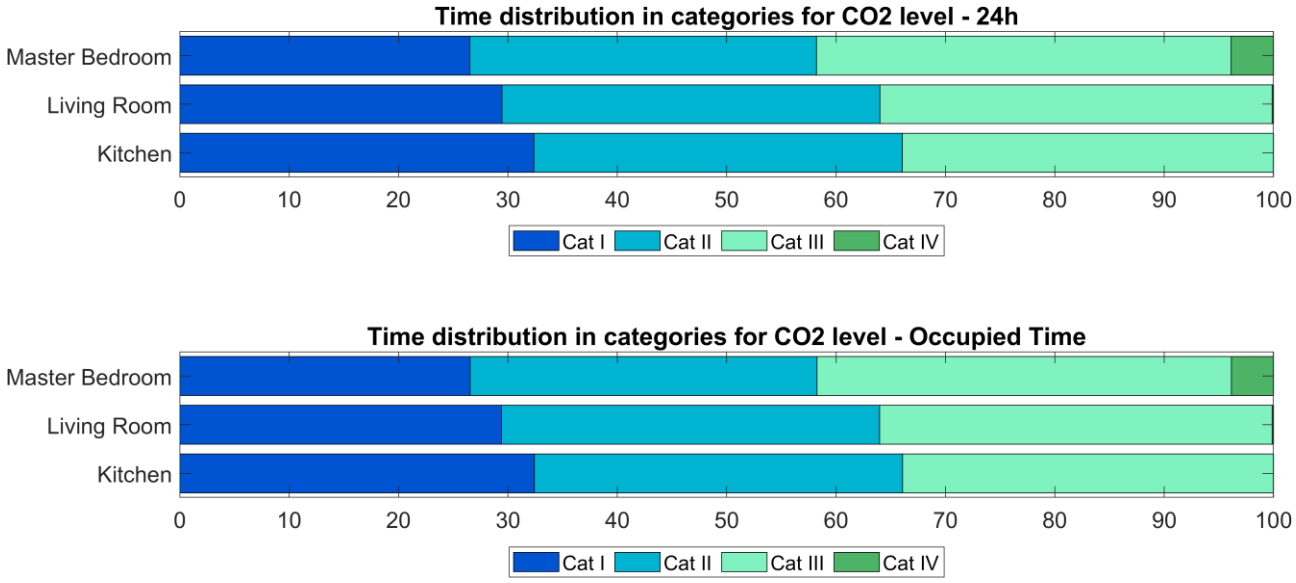


Figure 3.19: Percentage of time in each Category for CO_2 level during a year

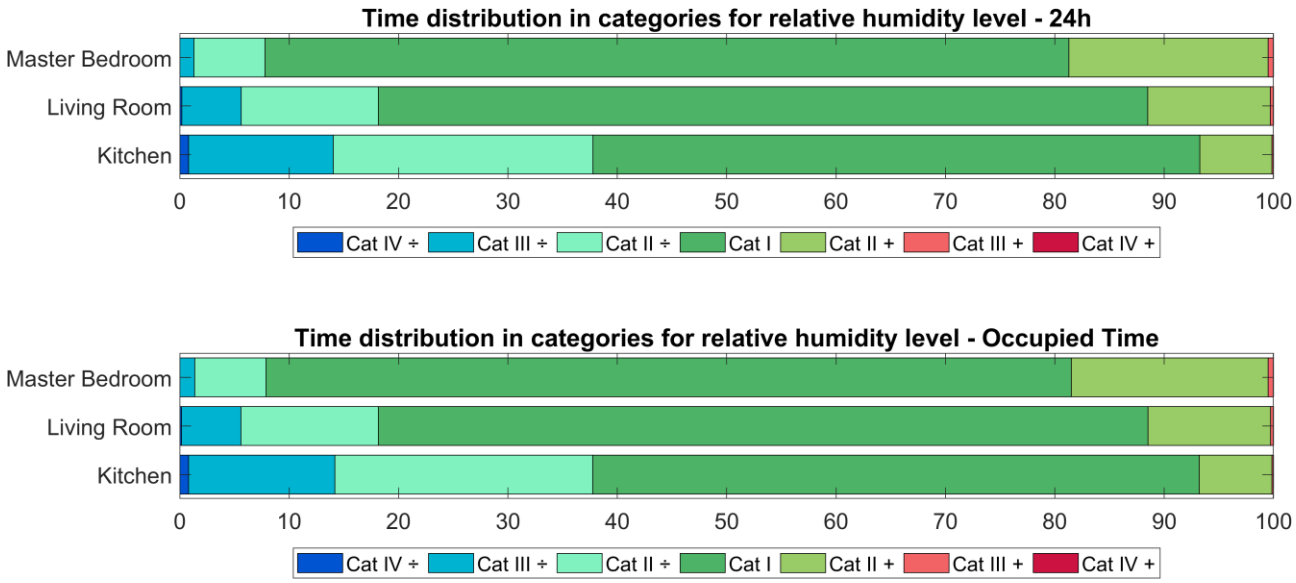


Figure 3.20: Percentage of time in each Category for relative humidity level during a year

3.2.3 Indoor air quality and window activation

The following graphs visualize the quality of indoor air, in relation to window opening. Like thermal comfort, it is considered that the conditions for good indoor air quality are met when the criteria for Category II are fulfilled. Both CO_2 level and relative humidity are taken into consideration. Thus, comfort conditions are achieved when the criteria for both parameters are fulfilled. The activation of windows can be realized either automatically or manually. For the kitchen/ dining room, the opening of the skylight is also taken into consideration, apart from the window. The data of CO_2 level and relative humidity are taken from the IC-meters, since they are considered more reliable.

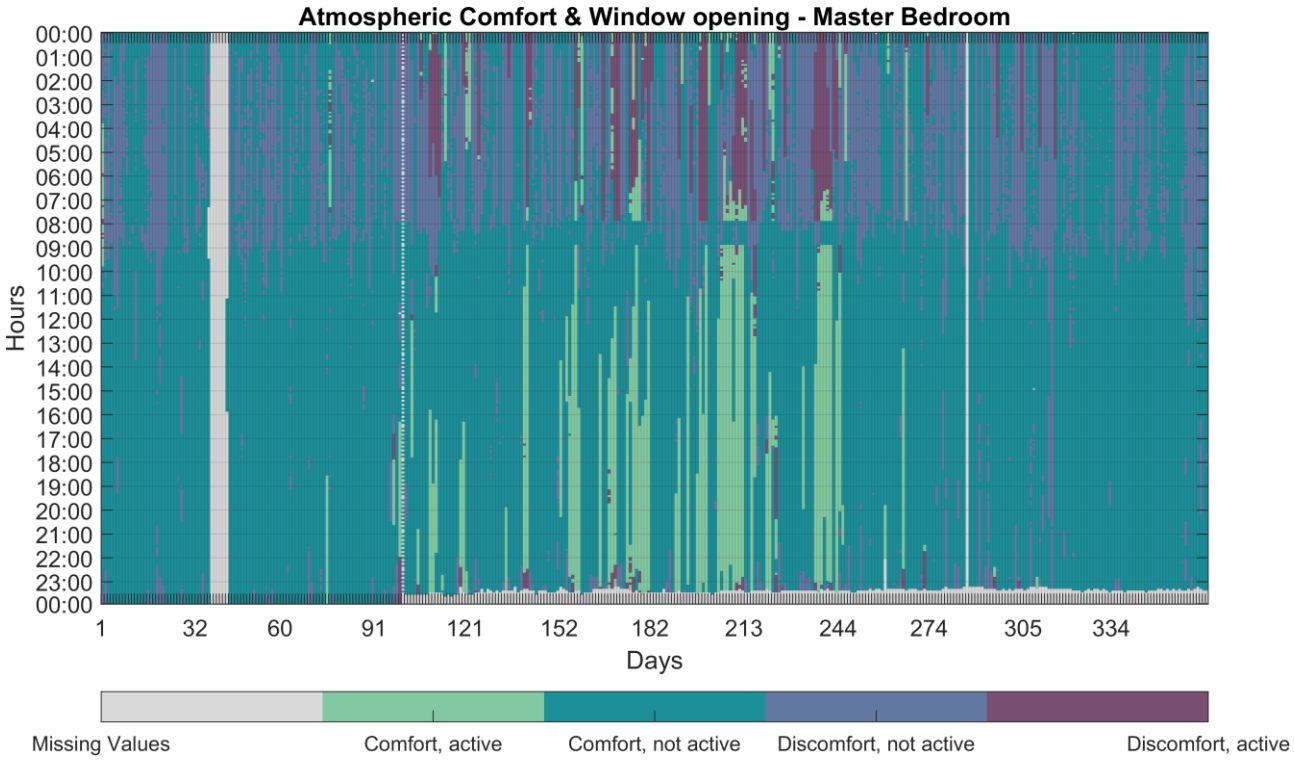


Figure 3.21: Indoor air quality in relation to window opening – Master bedroom

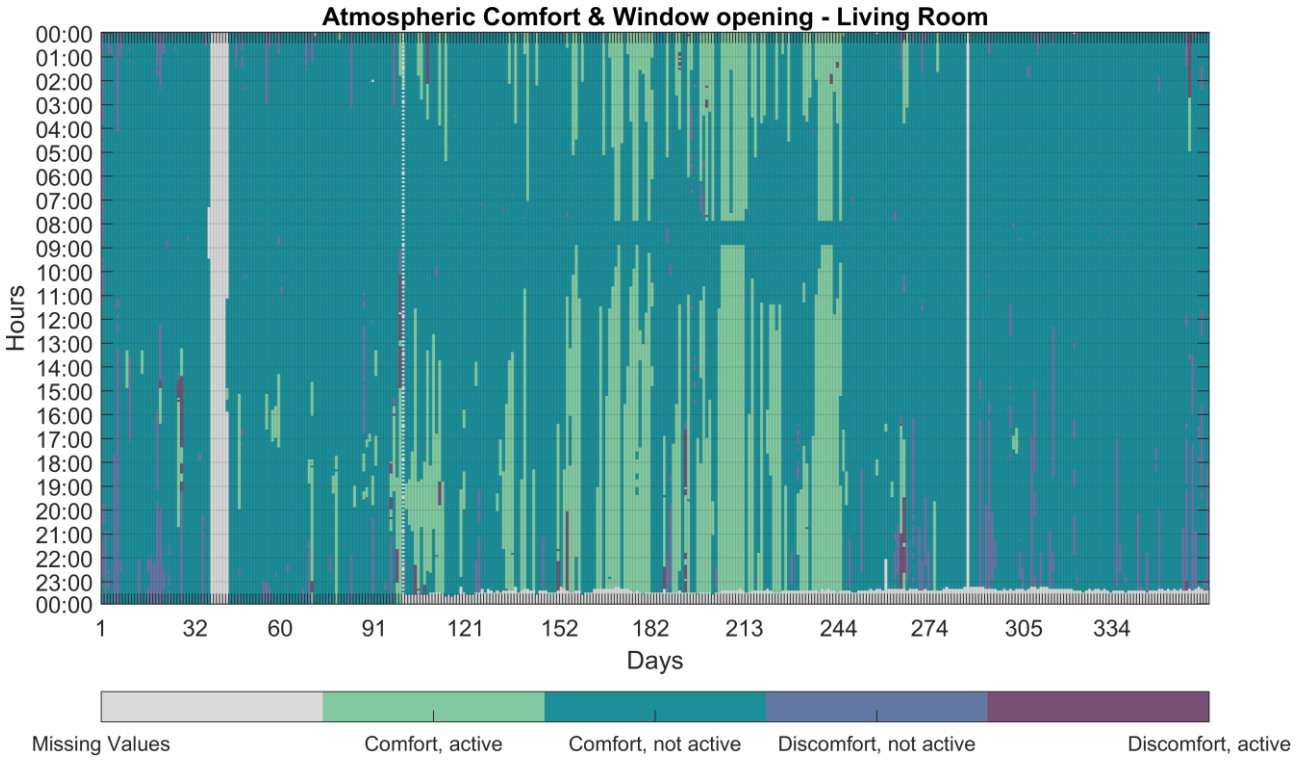


Figure 3.22: Indoor air quality in relation to window opening – Living room

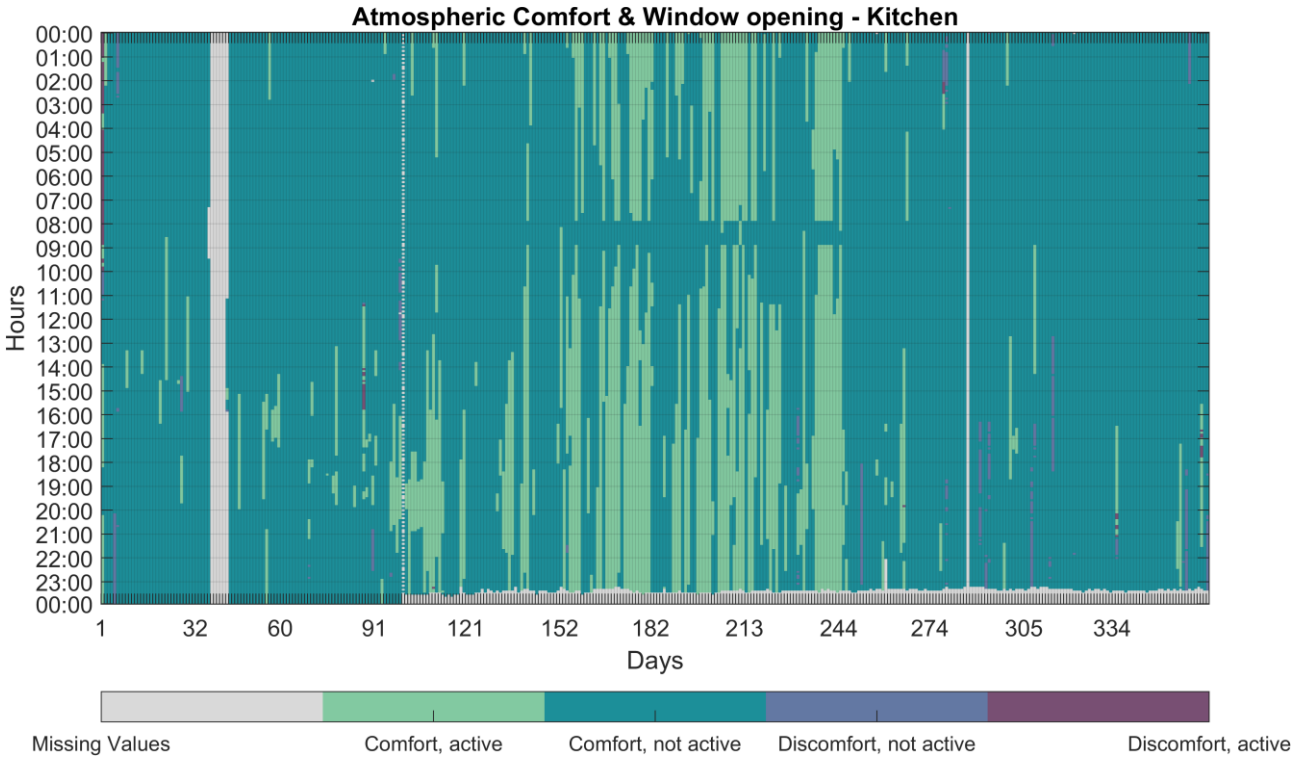


Figure 3.23: Indoor air quality in relation to window opening – Kitchen/ Dining room

4. Ventilation Air Flow Rate

The following graphs describe the ventilation airflow rate during 2019.

4.1 Airflow rate and average CO_2 level

The CO_2 level is calculated as an average hourly level of the Master bedroom, living room and kitchen combined.

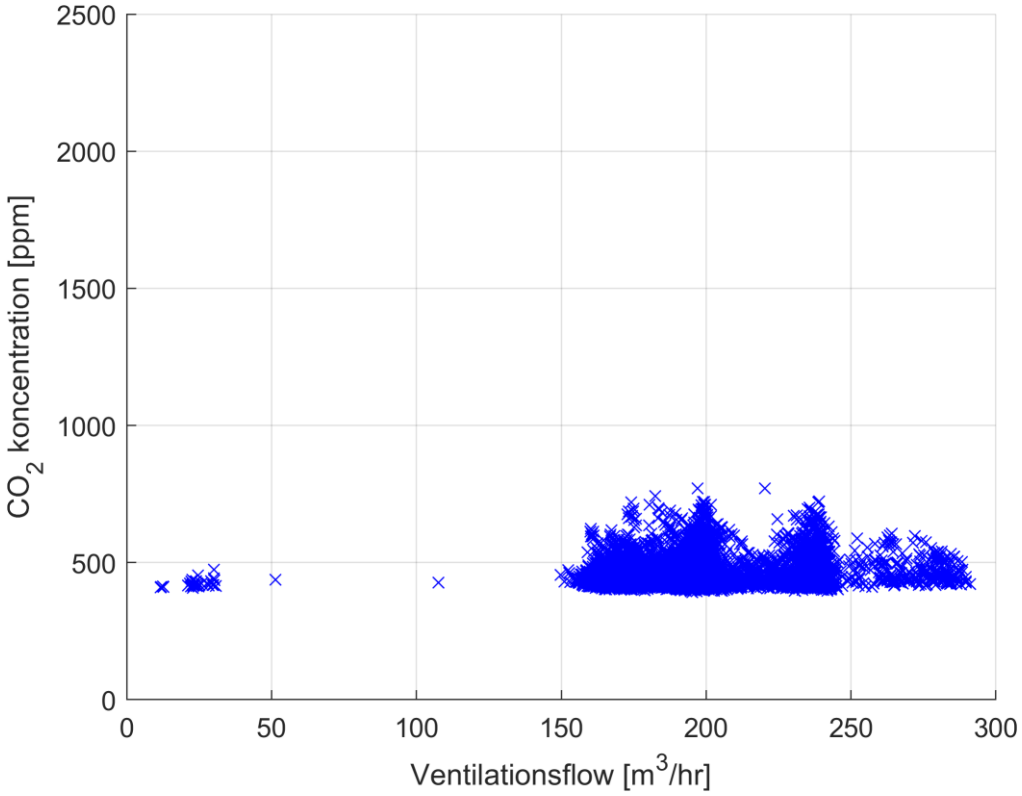


Figure 4.1: Ventilation flow rate compared to mean co2 level.

4.2 Cumulative outlet airflow and CO_2 level

The CO_2 level is calculated as a hourly average.

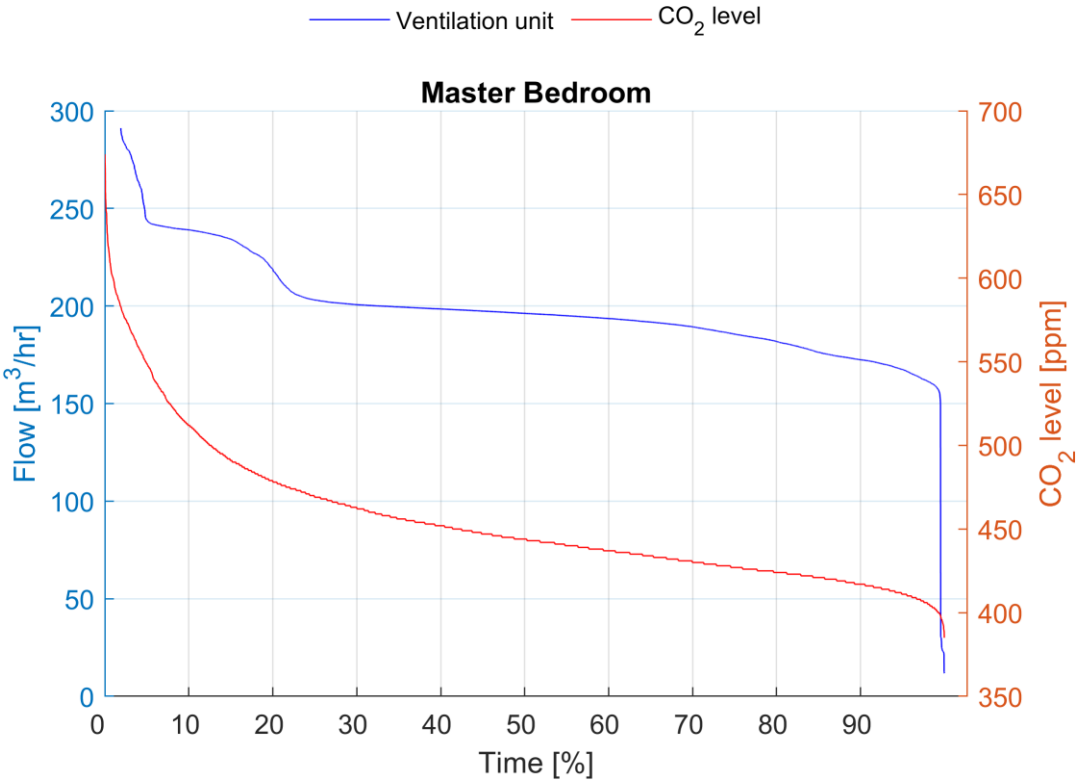


Figure 4.2: Cumulative ventilation flow and CO_2 level (Master bedroom)

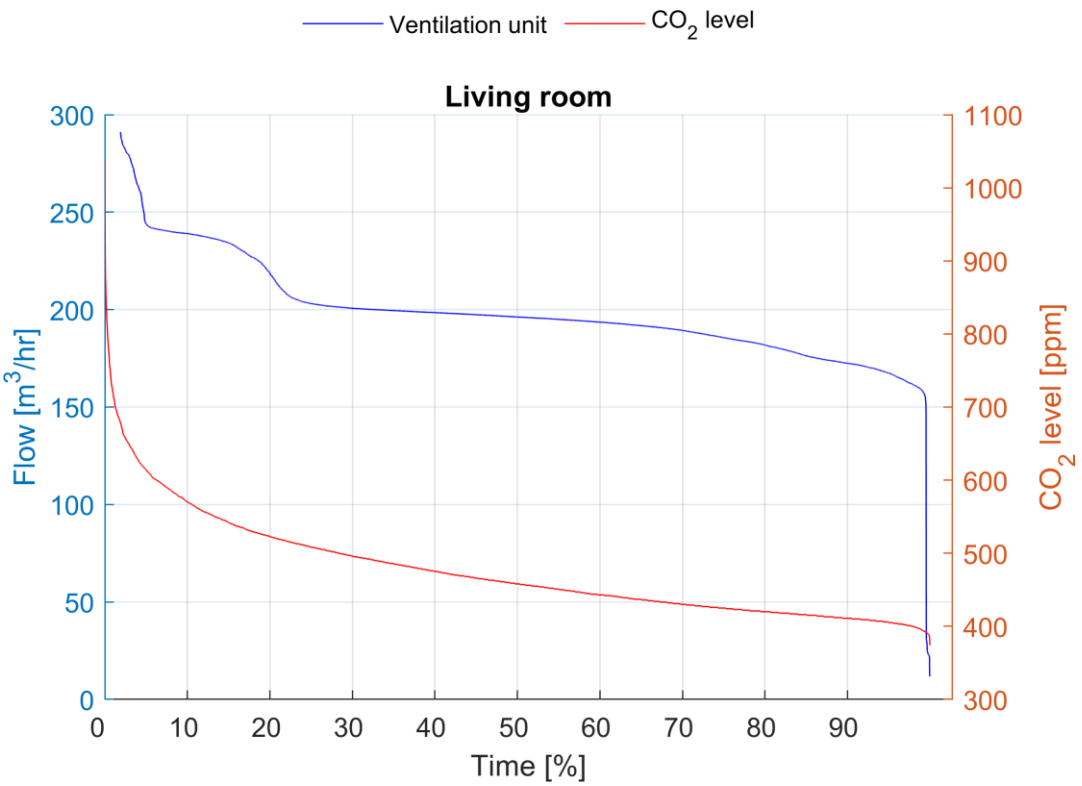


Figure 4.3: Cumulative ventilation flow and CO_2 level (Living room)

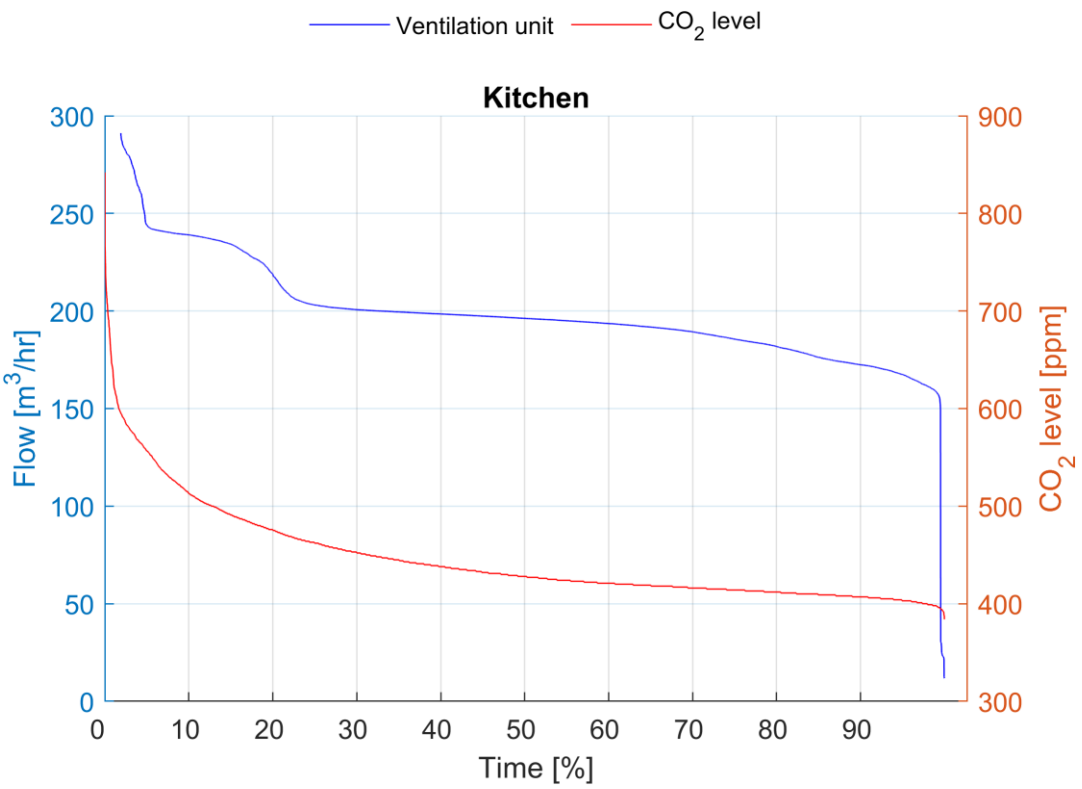


Figure 4.4: Cumulative ventilation flow and CO_2 level (Kitchen)

4.3 Cumulative outlet airflow and airflow temperatures

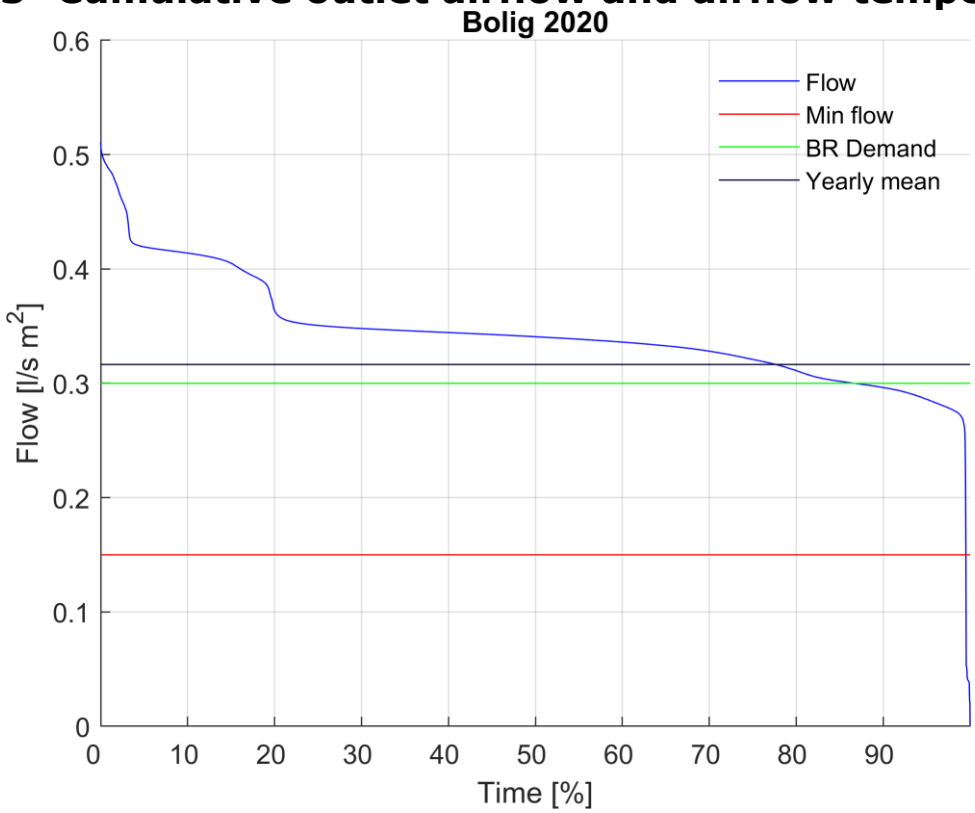


Figure 4.5: Cumulative ventilation flow compared to demand from the building regulation, minimum allowed flow and yearly acchived mean flow

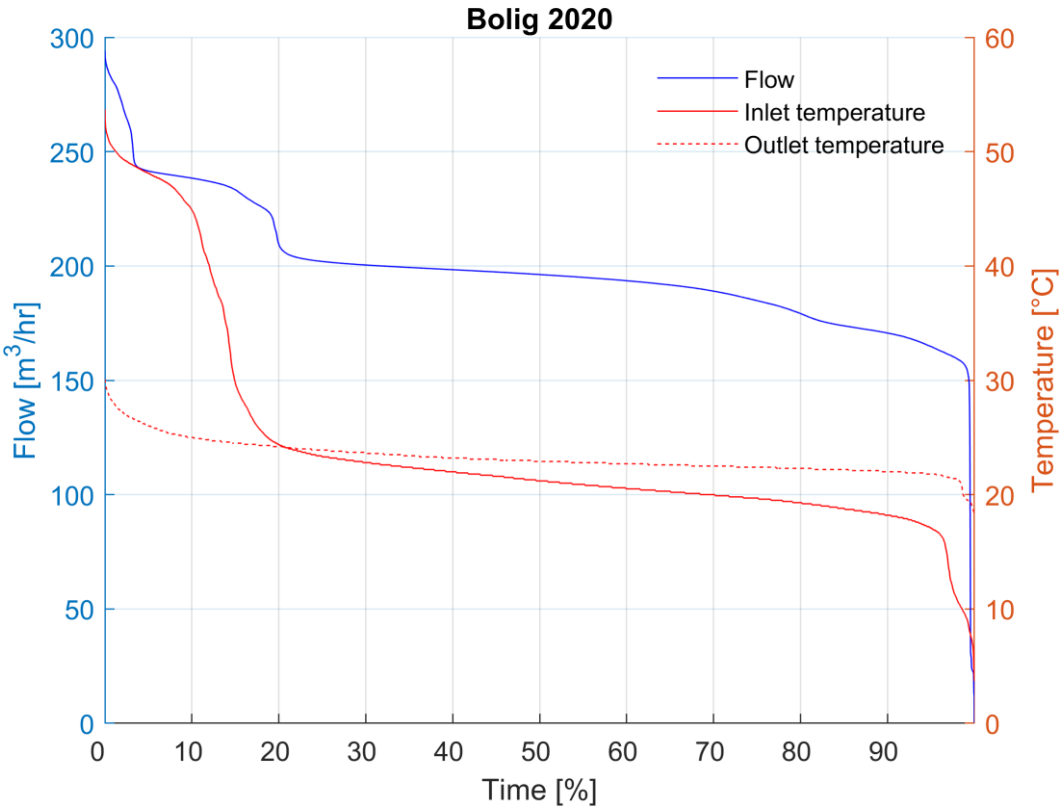


Figure 4.6: Cumulative ventilation flow and inlet and outlet air temperature

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